Fruiting season and seed germination of coastal vine forest species from East Point Recreational Reserve, Northern Territory, Australia

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Abstract

Fires, storms, cyclones and human activities impact coastal vine forest communities around Darwin. To restore these communities after such disturbance, information on the fruiting season and seed germination of native species is important for collecting and propagating their seeds. We studied the seasonal occurrence of fruiting and the requirements for seed germination of 19 coastal vine forest species in Darwin's East Point Recreational Reserve. Fruiting and seeding were seasonal, nine species set fruit during the Wet season and 10 species set fruit during the Dry season. Seed fall lagged by two or three months behind fruiting. Thirteen of the species did not have any seed dormancy and five species were treated to break dormancy. With the application of the most effective germination treatment, two species started to germinate within two days, and all except two species commenced germinating within 14 days. Maximum germination of all species had occurred within 30 days. Because dispersal of mature seeds of most species occurs over only one or two months each year, fire impacts prior to dispersal could disrupt seed availability for at least one year.

Introduction

Coastal vine forest is a dry rainforest community established on a seasonally dry substrate with evergreen, deciduous and semi-deciduous species (Russell-Smith 1991). It is a unique community which supports a wide range of wildlife and native flora. Coastal vine forest in the Northern Territory is prone to disturbance, including cyclones and urban development. As it experiences an extended drought during the Dry season, it may also be impacted by fire.

One such iconic coastal vine forest community is at East Point Recreational Reserve in Darwin. This remnant forest was severely affected by disturbances prior to 1975 and has required active restoration (Franklin *et al.* 2010). One successful approach to restoring seasonally dry tropical rainforest such as this is to introduce a range of overstory and understory species to restore ecological function and structure (Blakesley *et al.* 2002). Native species are introduced by either direct seeding or by planting their seedlings in revegetation trials (Doust *et al.* 2006). These species then promote the recruitment of additional floral diversity over time.

Knowledge of the fruiting season, seed germination and seed dormancy are important to collect seeds, propagate seedlings, and for nursery planning for revegetation activities (Baskin & Baskin 2014; Thusithana *et al.* 2018). A Wet-Dry seasonal climate results in fluctuations in rainforest fruiting and seed maturation (Cortés-Flores *et al.* 2019). Dry fruits, which have a woody and drier pericarp with small, low-water-content seeds are produced in the Dry season. By contrast, in the Wet season, fleshy fruits are produced. They have a higher moisture content as well as nutritive and fleshy pericarps to attract birds and mammals to disperse their seeds (Griz & Machado 2001; Vieira & Scariot 2006). Fruiting phenology and seed fall periods for dry rainforest coastal vine forest species are crucial because fruiting/seed fall is strongly seasonal, can occur infrequently, and its timing can vary between dry rainforest patches (Bach 2002). Therefore, site specific monitoring is crucial to record the exact fruiting season of species for seed collection.

Other factors affecting propagation of rainforest species from seeds include seed maturity, seed germination and dormancy. There are few studies for coastal rainforest species in Australia and most such information is from Queensland. Seed maturity is when the seed or fruit disconnects from the parental plant. At this stage, the seed has gained maximum dry weight, vigour and potential to germinate (Baskin & Baskin 2014). At immature stages, the seeds may fail to germinate, or lack vigour, or may be more prone to disease (Hay & Smith 2003). It is vital to collect mature (ripe) seeds for germination or to store them for future use (Baskin & Baskin 2014). Therefore, it is essential for the collector to determine when the seed is mature and to time the harvest accordingly (Schmidt 2000). Seed maturation is also seasonal. Dry fruits have seeds that generally mature in the late Dry season to be dispersed by air, gravity or ballistic explosion (Griz & Marchado 2001). Greater wind circulation occurs in the open canopy during the Dry season and this favours long distance dispersal of seeds by wind (Griz & Marchado 2001). For seeds that are dispersed by ballistic methods, the Dry season air dehydrates the pericarp causing the fruit to eject the seeds into the air (Griz & Marchado 2001). In contrast, most fleshy fruited seeds mature during the Wet season. Such seeds have higher moisture; therefore, they time their maturation during the Wet season to germinate soon after detachment from the parental plant.

For a seed to germinate, it must be viable, non-dormant and exposed to optimum environmental conditions such as light, moisture, temperature and oxygen (Baskin & Baskin 2014). Seed viability is the potential for a seed to germinate under those suitable environmental conditions. Many dry seasonal rainforest species lose viability due to desiccation during the Dry season drought (Khurana & Singh 2001). Viability is also affected by pre-dispersal predation of fruit, which causes physical damage to the seeds and affects the seed fill (Tiansawat *et al.* 2017). Viable seeds that fail to germinate in the presence of suitable moisture, temperature and light conditions are considered to be dormant (Baskin & Baskin 2014). Baskin & Baskin (2014) consider a seed lot is dormant if 50% or more of the viable seeds take more than one month to germinate. In a seasonally dry rainforest, a greater proportion of species produces dormant seeds when compared to an evergreen rainforest; Baskin & Baskin (2014) report that 66% of the 221 dry seasonal rainforest species have dormant seeds.

Dormancy is primarily found in species which disperse seeds in the Dry season. This prevents germination during the infrequent early Dry season rains, which are unfavourable for seedling establishment and survival (Khurana & Singh 2001). Seed coat dormancy and embryo dormancy are the two main types of dormancy possessed by rainforest species (Baskin & Baskin 2005). Seed coat dormancy may be due to an impermeable seed coat preventing water uptake or inhibitors present in the seed coat or fruit. Such seeds require either mechanical scarification, or hot water treatment, or chemical treatment to make the coat permeable. Embryo-related dormancy is due to the presence of inhibiting factors such as low levels of growth-promoting hormones in the embryo. This can be overcome by external application of gibberellic acid. Treating seeds to break dormancy leads to faster production time in the nursery, lowers nursery costs and gives greater control over seedling planting times. Information on the most suitable dormancy-breaking mechanisms for these coastal vine forest species are published in Thusithana *et al.* (2018), including the effects of individual dormancy-breaking treatments on cumulative germination and the days taken for the seeds to achieve the maximum germination after dormancy-breaking treatments are applied.

In this study, we investigated when fruiting and seed release occur in the coastal vine forest species present in the vine forest patch at East Point Recreational Reserve in Darwin. We also, for the first time, give an overall summary of germination characteristics of non-dormant seeds and of dormant seeds that have been treated with the best dormancy-breaking treatment, including the number of days until seeds started to germinate, and the number of days until germination ceased.

Materials and methods

Study site

The study site was the coastal vine forest at East Point Recreational Reserve, approximately 6 km north of Darwin, Northern Territory. This reserve is situated on a peninsula that is dominated by monsoonal coastal vine forest. The topography is a flat, lateritic plateau to a maximum altitude of 11.2 m above sea level, which is well-drained, but there is no permanent natural water (Franklin *et al.* 2010).

East Point Recreational Reserve was subjected to several anthropogenic activities and natural events which caused extensive vegetation clearance from 1932–1963 (Franklin *et al.* 2010). Revegetation of the area was started by the Northern Territory Government in 1974, then Darwin City Council took over the management of forest rehabilitation in 1984. Currently, the Reserve supports 14 ha of remnant forest and differently aged patches of rehabilitated forest, dating from 1964–1970, 1974, 1985–1991, 1992–2002 and 2003–2016. The history of the site is described in Franklin *et al.* (2010).

Fruiting phenology and morphology

Twelve plots, each 20 m by 10 m in size, were established in the coastal vine forest in the East Point Recreational Reserve in May 2015. Flowering and fruiting phenology of 19 species (Table 1) were assessed by monthly visits to the plots from May 2015 to April 2017. The months were categorised into seasons such as early Wet, late Wet, early Dry and late Dry based on the rainfall pattern as described in Thusithana (2020). Fruiting patterns were related to these seasons.

Table 1. Ecological attributes and the fruit type of the study species.

Common name and species name	**Family**	**Pioneer/climax, life form and stratum**	**Fruit type**	**No. seeds per fruit**
Pioneer species				
Crab Eye Vine *Abrus precatorius*	Fabaceae	Pioneer Vine	Follicle	10–14
Red Ash *Alphitonia excelsa*	Rhamnaceae	Pioneer Canopy tree	Drupe	4–5
Gambrion *Breynia cernua*	Phyllanthaceae	Pioneer Midstory shrub	Berry	5–6
Kapok Tree *Bombax ceiba*	Malvaceae	Pioneer Canopy tree	Capsule	>40
Broad-winged Hop Bush *Dodonaea platyptera*	Sapindaceae	Pioneer Midstory shrub	Capsule	1
Coral Tree *Erythrina variegata*	Fabaceae	Pioneer Midstory shrub	Follicle	1–2
Cluster Fig *Ficus racemosa*	Moraceae	Pioneer Canopy tree	Syconium	>100
Lime Berry *Micromelum minutum*	Rutaceae	Pioneer Understory shrub	Berry	1
Cheese Fruit *Morinda citrifolia*	Rubiaceae	Pioneer Midstory tree	Composite fruit	>40
Opilia amentacea	Opiliacae	Pioneer Vine	Berry	1
Strychnine Tree *Strychnos lucida*	Loganiaceae	Pioneer Canopy/midstory tree	Berry	2–4
Peanut Tree *Sterculia quadrifida*	Sterculiaceae	Pioneer Canopy tree	Follicle	5–6
Dediteh *Wrightia pubescens*	Apocynaceae	Pioneer Midstory shrub	Follicle	>100
Climax species				
Archer Cherry *Aidia racemosa*	Rubiaceae	Climax Canopy tree	Berry	3–5
Ebony *Diospyros calycantha*	Ebenaceae	Climax Canopy /midstory tree	Berry	5–7
Australian Ebony *Diospyros compacta*	Ebenaceae	Climax Canopy/midstory tree	Berry	4–6
Ebony *Diospyros rugosula*	Ebenaceae	Climax Midstory shrub	Berry	4–6
Yellow Tulipwood *Drypetes deplanchei*	Putranjivaceae	Climax Canopy/midstory tree	Drupe	1
Pink-fruited Berry *Glycosmis trifoliata*	Rutaceae	Climax Shrub	Berry	1

Mature seeds/fruits of 19 native species were collected from at least 10 adult individuals per species randomly (Figures 1, 2) in May 2015. Fruit type and number of seeds per fruit were noted for each species. Seeds were collected when the fruits had reached dispersal maturity (Table 2). Dispersal maturity of the seeds was initially identified when fallen fruits were found around the maternal plants. Firmness of the fruit and colour of the pericarp were assessed. With maturity, the firmness of the fruit reduces with accumulation of more loosened pulp or dry mesocarp. The colour of the pericarp of many species turns from green to grey green, or brown, or into other bright colours when ripe (Schmidt 2007). Fruits were cut into halves to check the colour of the seed coat. With maturity, the colour of the seed coat typically turns from hyaline to brown and black. The seeds of dehiscent fruits were collected when the valves, scales and the margin of the pericarp started to break off.

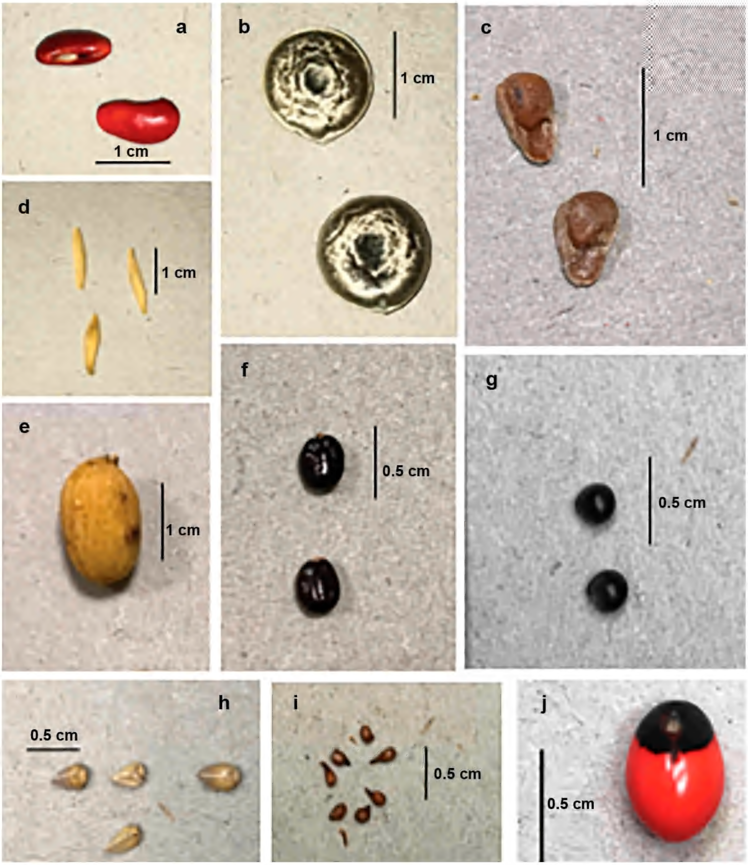

Figure 1. Seeds of pioneer species. **a.** *Erythrina variegata*, **b.** *Strychnos lucida*, **c.** *Morinda citrifolia*, **d.** *Wrightia pubescens*, **e.** *Opilia amentacea*. **f.** *Alphitonia excelsa*, **g.** *Dodonaea platyptera*, **h.** *Breynia cernua*, **i.** *Ficus racemosa*, **j.** *Abrus precatorius*.

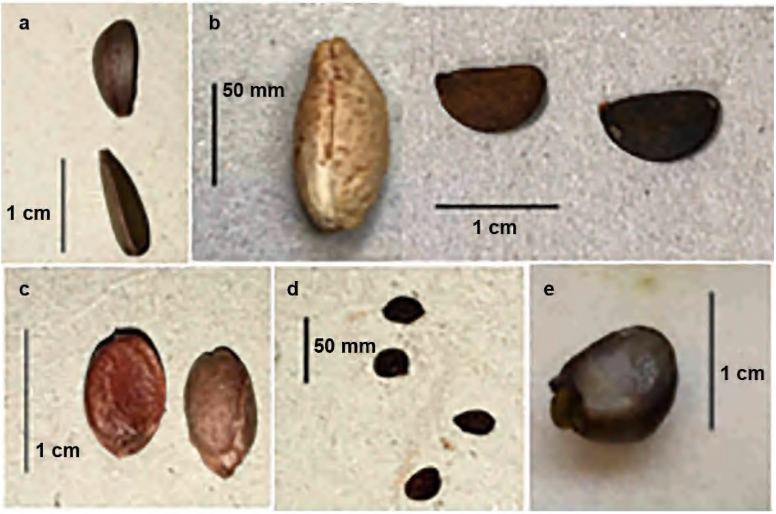

Figure 2. Seeds of climax species. **a.** *Diospyros calycantha,* **b.** *Drypetes deplanchei* (left), *Diospyros rugosula* (right), **c.** *Diospyros compacta,* **d.** *Aidia racemosa,* **e.** *Glycosmis trifoliata.*

During seed collection, either branches of small trees and shrubs were cut with secateurs or the fruits were hand-picked. For species that released seeds quickly, paper bags were tied around the branchlets before the branchlets were pruned. Seeds collected from different trees were bulked together for each species. Viability, germination, imbibition and the effectiveness of dormancy-breaking treatments were assessed within a week after seed collection (Thusithana *et al.* 2018).

Seed germination and seed dormancy

Germination assessments were carried out for four replicates of 25 seeds per species. Seeds were germinated on moist filter paper in 9 cm diameter Petri-dishes in an incubator maintained at 30 °C, as this temperature is the average Wet season temperature recorded in the habitat. The number of days to initial germination and to maximum germination, following the most effective seed dormancy treatment (Thusithana *et al.* 2018), were recorded. The mean number of days for untreated seeds to germinate (including untreated dormant seeds) is included for comparison from Thusithana *et al.* (2018).

Viability test

Three samples each with 25 seeds were subjected to the cut test. Seeds with milky, unfirm, mouldy, decayed, shrivelled or rancid-smelling embryos and seeds with a missing embryo were scored as inviable. Seeds with a white/green firm embryo were scored as viable.

Results

Fruiting was seasonal and varied between species and between years (Table 2). For a particular species, fruit production occurred either in the Dry or in the Wet season, but never both. Nine species fruited in the Wet season and 10 fruited in the Dry season. For most of the Dry season fruiting species, fruiting peaked between August to October (late Dry season) and the species fruiting in the Wet season peaked during December to February (early Wet season). Most species only dispersed mature seeds within a single month but *Micromelum minutum* dispersed its seeds over a four month period. Fruit fall lagged by one to two months after the fruits were first observed on the tree. The exceptions were *Strychnos lucida* and *Wrightia pubescens*, for which fruit fall occurred five to six months after the fruits were first observed on the tree.

Table 2. Fruiting and fruit fall phenology of study species (May–July: early Dry; August – October: late Dry; November–January: early Wet: February–April: late Wet). Open symbols indicate fruits were observed on the tree and solid symbols indicate mature fruit; dispersing in Year 1 (May 2015–April 2016) (△■) and Year 2 (May 2016–April 2017) (■□).

Species	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**January**	**February**	**March**	**April**
Pioneer species												
Abrus precatorius				△□	△■	▲						
Alphitonia excelsa				□	△▲■	▲■						
Bombax ceiba			△	△□	▲■							
Breynia cernua									△	△□	▲■	
Dodonaea platyptera		△□	△□	▲■								
Erythrina variegata				△	△□	▲■						
Ficus racemosa								△□	△□	▲■		
Micromelum minutum				△□	△□	△□	▲■	▲■	▲■	▲■		
Morinda citrifolia									△□	△□	▲■	
Opilia amentacea								△□	▲■	■		
Sterculia quadrifida				△□	△□	▲■						
Strychnos lucida	□	△□	△□	△□	▲■	▲■	■				△□	△
Wrightia pubescens	□	△□	△□	▲■	▲■	▲■					△□	△
Climax species												
Aidia racemosa								△	△□	△□	▲■	▲
Diospyros calycantha			△□	△□	▲□	▲■						
Diospyros compacta								△	▲■	▲■		
Diospyros rugosula	□	■	■	■						□	△□	△
Drypetes deplanchei								△□	▲■	▲■		
Glycosmis trifoliata						△□	▲■	■				

Species which set fruit in the Wet season commonly had a fleshy pericarp (berry type). Dry season fruiting species had fruits that were drupes, follicles or capsules (Table 1). The berry was the most common fruit type recorded among the 19 species. Six species had a single-seeded fruit while *Ficus racemosa*, *Wrightia pubescens* and *Morinda citrifolia* had more than 100 seeds per fruit. The number of seeds per fruit found in the remaining species varied between 5 and 25 (Table 2).

All of the studied species had 100% seed fill except for *Micromelum minutum* and *Diospyros rugosula*, which had 96% and 97% viability, respectively.

Table 3. Seed germination characteristics for coastal vine forest species following optimum germination and seed dormancy treatments identified in Thusithana *et al.* (2018). MGL, mean germination length of seeds to achieve the maximum germination % without any treatment for comparison to optimally treated seeds; G%, maximum cumulative germination % of non-treated and treated seeds; First G, days until first germination of non-treated and treated seeds; Max. G (days); days taken for seeds with optimal treatment to achieve the maximum cumulative germination %. ± is standard error mean. Viability (%): seeds that had a firm white embryo for cut test. HW = hot water; GA_3 = gibberellic acid. Max. G % information for all species, and MGL data, are from Thusithana *et al.* (2018).

Species name	**MGL (days)**	**Viability (%)**	**Optimum treatment**	**G (%)**	**First G (days)**	**Max. G (days)**
Abrus precatorius	14 ± 3	100.0 ± 0.0	HW 95°C for 5 min.	100.0 ± 0.0	3	26
Alphitonia excelsa	>30	100.0 ± 0.0	HW 88–92°C for 5 min.	93.6 ± 4.1	4	19
Bombax ceiba	12 ± 2	100.0 ± 0.0	Nil	92.0 ± 3.4	2	18
Breynia cernua	15 ± 0	100.0 ± 0.0	Nil	85.6 ± 5.2	12	20
Dodonaea platyptera	>30	100.0 ± 0.0	HW 88–92°C for 1 min.	93.7 ± 3.9	6	20
Erythrina variegata	13 ± 1	100.0 ± 0.0	Nil	94.4 ± 2.7	7	22
Ficus racemosa	12 ± 1	100.0 ± 0.0	Nil	81.6 ± 5.3	11	15
Micromelum minutum	6 ± 0	96.0 ± 2.3	Nil	100.0 ± 0.0	3	10
Morinda citrifolia	>30	100.0 ± 0.0	Scarification + 1000ppm GA_3	56.8 ± 4.2	21	28
Opilia amentacea	9 ± 1	100.0 ± 0.0	Nil	70.4 ± 3.7	5	20
Sterculia quadrifida	7 ± 0	100.0 ± 0.0	Nil	96.0 ± 1.3	5	11
Strychnos lucida	17 ± 0	100.0 ± 0.0	Nil	99.2 ± 0.2	12	20
Wrightia pubescens	8 ± 1	100.0 ± 0.0	Nil	94.4 ± 2.0	2	14
Diospyros calycantha	14 ± 1	100.0 ± 0.0	Nil	96.8 ± 3.2	9	28
Diospyros compacta	10 ± 1	100.0 ± 0.0	Nil	96.0 ± 3.1	6	16
Diospyros rugosula	20 ± 1	97.3 ± 2.7	Nil	55.2 ± 6.4	17	29
Drypetes deplanchei	>30	100.0 ± 0.0	Scarification + 1000 ppm GA_3	79.2 ± 4.6	7	20
Glycosmis trifoliata	3 ± 0	100.0 ± 0.0	Nil	92.0 ± 2.3	4	4

Most species with non-dormant seeds had their seeds start to germinate within a week of incubation (Table 3). The exceptions were *Strychnos lucida*, *Breynia cernua* and *Diospyros rugosula*, which took 12–19 days for the first seed to germinate. Most species were not dormant, and all species completed germination within 29 days if treated appropriately.

Discussion

Fruiting phenology and fruit or seed collection

Fruiting of individual species was limited to a particular season and was often only for a short duration. Such seasonality in fruiting was also reported in the seasonally dry rainforest patch at Gunn Point, Shoal Bay, Northern Territory, by Bach (2002) and Franklin & Bach (2005). Similarly, in seasonally dry rainforest in Panama, Sautu *et al.* (2006) reported that seeds of 32, 29, and 33 species were dispersed during the Dry (January–March), early rainy (April–July), and late rainy (August–December) seasons, respectively. However, that study reported that most species fruited over more than two months, with some species fruiting for seven months, and one species for 11 months. In our study four of the six climax species dispersed seeds in the Wet season, whereas eight of the 13 pioneer species dispersed seeds in the Dry season. The pioneer tree species tended to disperse seeds at the end of the Dry season but the timing was variable for shrubs. As reported by Franklin and Bach (2005), although individual species had short intervals of seed and fruit dispersal, across all the species there was some seed dispersal in every month (except for May in our study).

Fires can have a substantial impact on fruit production, and a fire impacting a remnant forest is likely to affect fruits of some species no matter what time of the year it occurs. For each species there is a brief period each year when fruits are shed. This means that a fire impact would likely affect the availability of mature fruit for at least 12 months. While there are direct impacts on fruit if a fire occurs when they are maturing, early season fires can impact ovule success through affecting pollination and by damaging developing flowers, even if destruction of foliage and branches does not occur (Setterfield 1997).

Phenological data on fruiting and seed shed are important when planning for revegetation of disturbed dry rainforest communities. The phenological data can be used to produce monthly prognoses for species and help to plan seed collection, plan seedling stock production and evaluate the availability of seedlings before the revegetation trials. This will assist in ensuring that species are not absent from plantings due to lack of seeds.

Different types of fruit were observed in the study species. Dry season fruiting species produced follicles, pods and capsules, while the fruits of Wet season fruiting species were berries and drupes. Information on the type of fruit is crucial for efficiently collecting seeds. Species which bear capsules, pods, follicles and cones open or split on maturity, allowing the seeds to be shed by wind or gravity. The exact time of seed release is hard to predict. Bagging the seed heads with a breathable lightweight fabric (Murphy & Dalton 1996) will capture the seeds as soon as they are shed. One difficulty is that most local rainforest species are zoochorous (i.e. they have spores or seeds dispersed by animals) (Bach & Price 2005; Franklin & Bach 2006) and their fleshy and bright coloured fruits are likely to be eaten by birds, insects or other animals at the time of maturity. This results in physical damage to, and loss of, seeds while attached to the parental plant. Therefore, having nets around the branches before the fruits reach maturity assists in conserving fruits and viable seeds for collection.

Seed viability varies considerably between rainforest species and is commonly affected by pathogen attack/disease, predation, environmental variability, and by genetics (Khurana & Singh 2001). Seedling production is most efficient if seeds are of high viability as lower viability seed lots require collecting and sowing of more fruits and seeds to get sufficient seedlings. Seed viability can be assessed by determining the seed fill and by tetrazolium tests. Assessing seed fill is an important first indication of seed quality (Bellairs & Caswell 2016), and seed fill can be tested during the time of seed collection by pressing the seeds or cutting open the seed and checking for the presence of an embryo. If plants at a particular site have poor seed fill then the collection can be shifted to another site where seed fill is high. However, seeds can be filled with an intact embryo but not be viable. Tetrazolium testing detects whether filled seeds are metabolically active by staining living tissue red. As it requires at least two days, laboratory facilities and expertise, it is generally only carried out in commercial seed test laboratories. For these particular seed lots in this study, seed fill was greater than 96% (Thusithana *et al.* 2018), except for *Aidia racemosa*, which had 0% seed fill. Viability as assessed with tetrazolium and reported in Thusithana *et al.* (2018) was lower, but they found that most species had greater than 77% viability when assessed with tetrazolium, except *Diospyros rugosula* (52.0 ± 0.1%) and *Aidia racemosa* (0.0 ± 0.0%). Therefore testing seed fill by observation in the field would give a reasonable indication of the proportion of viable seeds for these species.

Seed treatment and germination

Some tropical seasonally dry rainforest species produce dormant seeds and Thusithana *et al.* (2018) determined that five of the species they studied had less than 10% germination if untreated, due to seed dormancy. The seeds of non-dormant species, and also of dormant species if the seeds were treated, commenced germination within two weeks (except *Morinda citrifolia*). Rapidly germinating seeds are more likely to escape seed death than slowly germinating seeds upon sowing because they escape seed predation by developing into saplings quickly (Kindt *et al.* 2006; Beckstead *et al.* 2007). We would agree with Farley *et al.* (2013) in not recommending the treatment of all dormant seeds, as retaining some dormant seeds gives a chance of success in the long term if adverse environmental conditions occur after the seeds are sown.

Most species in our trials did not require seed pre-treatment but if the five species with dormant seeds had the seeds treated, then germination was completed within 29 days. A hot water treatment improved the germination of *Abrus precatorius*, *Alphitonia excelsa* and *Dodonaea platyptera* (Thusithana *et al.*. 2018). Other studies also have shown that germination of *Alphitonia petrei* and of *Dodonaea petiolaris* was improved after hot water treatment (Turner *et al.* 2005, Turner *et al.* 2009, respectively). Seeds of *Abrus precatorius* have a thicker seed coat and require a higher temperature (95°C) to break dormancy. Two other species had dormant seeds that required treatment. *Morinda citrifolia* and *Drypetes deplanchei* had the seeds manually scarified and incubated in 1000 ppm gibberellic acid. Either mechanical scarification alone or together with gibberellic acid treatment is effective for *Drypetes deplanchei* and *Morinda citrifolia* but the combination of scarification with gibberellic acid gives highest germination (Thusithana *et al.* 2018). This is a typical response for species with physiological dormancy. Scarification abrades the seed coat, improving oxygen uptake into the seed, enhancing development of the embryo, and thus permitting the embryo to protrude from the seed coat (Côme & Tissaoui 1973). Although scarification improves the germination of seeds, it has drawbacks in large scale application. Intense tumbling of seeds within an abrasive medium can damage the embryo. Therefore, protocols need to balance sufficient scarification to promote germination without causing loss of seed viability due to damage. Application of gibberellic acid improves cell elongation in the embryo and enables the embryo to protrude from the seed coat (Baskin & Baskin 2014).

These species with dormant seeds that have germination promoted by hot water and scarification treatments, could also have germination enhanced by mild fires. Fire-stimulated species, such as Black Wattle (*Acacia auriculiformis*) and White Siris (*Albizia lebbeck*), are even more abundant in the standing vegetation and seed rain of revegetation patches at East Point than in the remnant forest (Thusithana 2020). Fire could stimulate germination of these species, increase their seedling recruitment and tend to cause divergence in the species composition from that of the remnant forest.

Conclusion

Introducing native dry rainforest species into suitable degraded habitat contributes considerably to local biodiversity and maintains the structural integrity of degraded/degrading patches. When small patches are impacted by fire, regional disturbance and urban development might limit natural dispersal of fruits and seeds. Therefore, seeds need to be actively sought to aid revegetation. However, a challenge for seed collection is that mature seeds are only dispersed during particular, often short, periods of the year. Current rehabilitation activities are often limited by seed availability. To maximise the likelihood of seed collection of a diverse range of species, it is necessary to understand the variation in fruiting phenology of the species and to be prepared to collect the seeds or fruits in the short window when they are available. To broaden the range of native species that are able to be introduced in the revegetation works, it is vital to understand their fruiting phenology, treat seeds appropriately, and be able to time germination to suit seedling propagation activities.

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Northern Territory Naturalist (2021) 30: 15-35 Research Article

A citizen science project in Ludmilla Bay, Darwin Harbour, helps identify invertebrates that fuel shorebird migration

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Abstract

The major aim of a citizen science project undertaken by Conservation Volunteers Australia was to increase knowledge and awareness of the shorebirds and the invertebrates that they rely on for food during their epic annual migratory journeys. Shorebirds were counted at 'Shorebird 2020' sites at Ludmilla Bay in Darwin Harbour during a count in 2018. A total of 897 individuals of 15 species of shorebirds (plus 59 individuals of 6 other vertebrate species) were recorded. Invertebrate samples were taken from 21 sites spread across Ludmilla Bay and from low to high tide at the same time of year. In total 63 samples were taken from 21 sites for invertebrates and they yielded a total of 34 species-level taxa. Taxa of annelids, molluscs, crustaceans, echinoderms, cnidarians, brachiopods and nemerteans were recorded. The invertebrate diversity was higher at either end of Ludmilla Bay, particularly around East Point at the northern end. Involving volunteers in this citizen science project was a key to its success in achieving its goals, including increasing awareness about these low-profile invertebrate and bird species. A total of 53 volunteer days were contributed by participants in this project, equating to over 400 person hours.

Introduction

Ludmilla Bay is one of nine Darwin shorebird count areas included in the 'Shorebirds 2020' annual census which collects data to contribute to protection of the area for shorebirds and increase the level of community awareness about this special group of birds. With the assistance of volunteers – local and international – Conservation Volunteers Australia (CVA) recorded the shorebirds and the invertebrates they rely on for their annual migratory journeys. Involving volunteers in this citizen science project was a key to the project's success in achieving the goals, including increasing awareness about these low profile species. Data collected as part of 'Shorebirds 2020' is instrumental in monitoring population trends for migratory shorebird species that regularly visit Australia and was a key driver for the listing of several migratory shorebird species, including the Eastern Curlew, which is listed as *Threatened under the Environment Protection and Biodiversity Conservation Act* (Weller & Lee 2018).

Ludmilla Bay (Figure 1), in the heart of suburban Darwin, is a mangrove-lined intertidal mud- and sand-flat with a creek entering at the western end. Nightcliff Rocks site, at the eastern end of the Bay, features a rocky platform and a rocky spit stretching out near the jetty. East Point sites A and B are on opposite sides of the Point. East Point A is a sandy/muddy area with mangroves. East Point B is rocky.

Shorebirds feed on mudflats at low tide and roost on higher ground at high tide including the rocky platforms and outcrops at each end of Ludmilla Bay. Some fly up to 12,000 km each way on their migration from the Northern Hemisphere, so they need to feed on their way in and out of Australia and other southern destinations. For this project, these shorebirds were counted at 'Shorebird 2020' sites at each end of Ludmilla Bay in August 2018. As expected, the shorebird counts showed an increase in bird numbers between August and January when most of the birds arrive in Australian sites from the Northern Hemisphere. Clearly, the area is a prime feeding area for visiting and resident shorebirds.

Shorebirds have bills of different length suited to their feeding habits (Figure 2). Eastern Curlews have the longest bill. If the mud-flat is permeable enough, a Curlew can push its bill, and even some of its head, 15 cm into the mud (Finn 2009). Therefore, the core samples for invertebrates (see below) were taken to 20 cm depth to ensure they sampled the mud to a depth that includes the reach of Eastern Curlews.

Threats to shorebirds include human disturbance (particularly from recreational activities), habitat loss and degradation, and invasive plants that can make feeding and roosting habitats unsuitable (Weller & Lee 2018).

The North Darwin Shorebird Area (Figure 1) starts at East Point to the north of the Darwin central business district, includes Ludmilla Bay which is the focus area of this project, and continues to Gunn Point at the eastern end of Shoal Bay. The North Darwin Shorebird Area is considered internationally significant (supporting more than 1% of the flyway population) for the migratory species Great Knot (*Calidris tenuirostris*), Greater Sand Plover (*Charadrius leschenaultia*), Red Knot (*Calidris canutus*) and Grey-tailed Tattler (*Tringa brevipes*). It is also considered nationally significant (supporting more than 0.1% of the flyway population) for several more migratory shorebirds: Black-tailed Godwit (*Limosa limosa*), Red-necked Stint (*Calidris ruficollis*), Little Curlew (*Numenius minutus*), Grey Plover (*Pluvialis squatarola*), Sanderling (*Calidris alba*), Lesser Sand Plover (*Charadrius mongolus*), Whimbrel (*Numenius phaeopus*), Terek Sandpiper (*Xenus cinereus*), Sharp-tailed Sandpiper (*Calidris acuminata*), Ruddy Turnstone (*Arenaria interpres*), Eastern Curlew (*Numenius madagascariensis*) and Wandering Tattler (*Tringa incara*) (Weller & Lee 2018).

A major aim of this project was to increase knowledge and awareness of the coastal benthic invertebrates of the area that constitute the diet of these shorebirds. The invertebrates are part of a complex and fascinating ecosystem about which little is known and they are commonly ignored in marine research and education (Baker *et al.* 2015). While invertebrate studies have been previously undertaken in and around Darwin, particularly in Darwin Harbour, little information from the results is available.

Invertebrate samples were taken from 21 sites spread across Ludmilla Bay and from low to high tide on several occasions in 2018. The number of invertebrates found in samples was similar in August, November and December. The density of invertebrates was greatest around the creek at the East Point end of the Bay and a smaller area at the Nightcliff end of the Bay.

This project aimed to take a snapshot of the habitat value of Ludmilla Bay's intertidal zone. As a Site of National Importance for Migratory Shorebirds, it is expected that the mud-flats there would support a high number of invertebrates that are suitable food for the shorebirds.

The project's objectives were to:

(i) assess the habitat value and increase understanding of the linkages of intertidal invertebrates and shorebird prey at Ludmilla Bay;

(ii) raise awareness of the environmental value of Ludmilla Bay;

(iii) recruit, train and manage community volunteers in local environmental monitoring activities.

A report summarising the results of these surveys (Winderlich & O'Dea, 2019) was prepared for CVA in April 2019. This article provides a more scientific summary of the program with additional information.

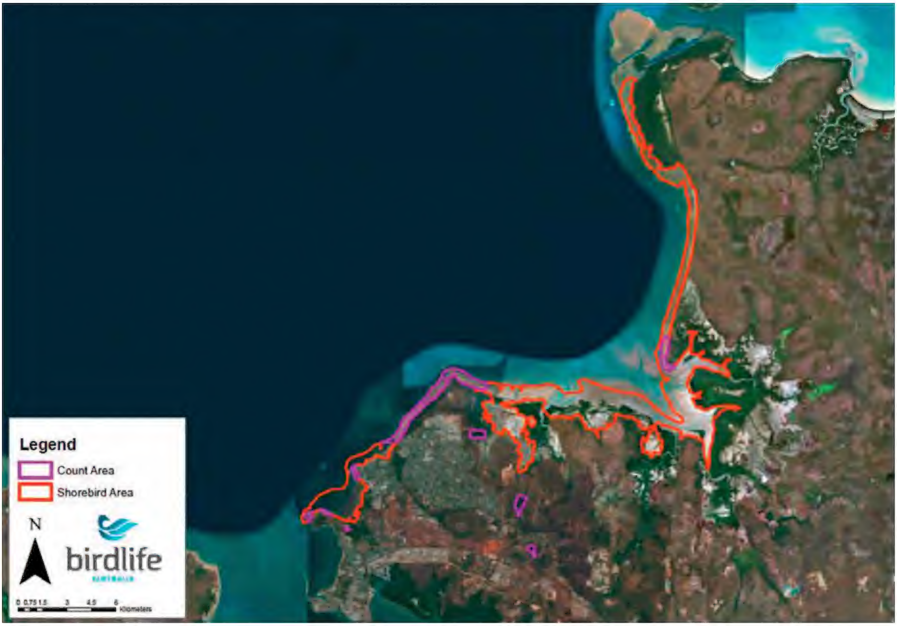


Figure 1. North Darwin Shorebird Area including Ludmilla Bay at the south-western end. Source: Birdlife Australia.

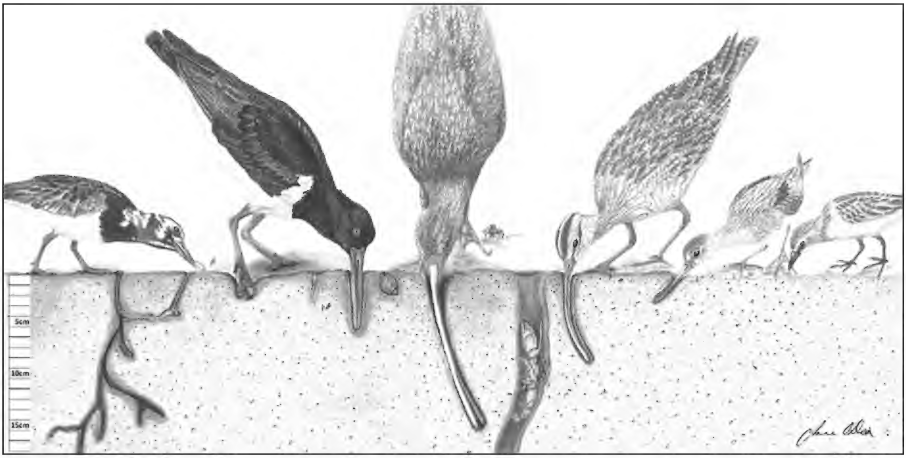


Figure 2. Shorebirds have bills of different lengths suited to their feeding habits. (Anne O'Dea)

Acronyms

BA	BirdLife Australia
CDU	Charles Darwin University, Darwin, Australia
CVA	Conservation Volunteers Australia
DENR	Northern Territory Government Department of Environment and Natural Resources
ECU	Edith Cowan University, Perth, Australia
MAGNT	Museum and Art Gallery of Northern Territory, Darwin, Australia

Materials and Methods

Bird counts

Bird count sites, as registered with BirdLife Australia, were visited at high tide. The counts were done on the same day as the August 2018 benthic samples, but within two hours either side of high tide. Counts were made at Nightcliff Rocks near the jetty where the shorebird sign is located, and also at East Point sites A and B (see co-ordinates in Table 1).

All water birds seen were counted and recorded with other observations on the 'Shorebird 2020' record sheet. The birds were identified using binoculars and a spotting scope. The results were registered on the 'Shorebird 2020' database where figures were also sourced for dates between October 2018 and January 2019.

Benthic invertebrate samples

The Ludmilla Bay invertebrate survey took place within the 'Shorebird 2020' area between East Point and Nightcliff beach, Darwin (see map Figure 7) at low tide. The dates the invertebrates were sampled were 28 and 29 August 2018, 27 and 28 November 2018, and 11 and 12 December 2018.

Sample sites were accessed by foot from either end of the Bay. Three samples were taken on seven transects roughly spread across the Bay (approx. 40 m between transects). The three samples were taken on each transect in the high, middle, and low intertidal zones (see co-ordinates in Table 1 and map Figure 7). The high intertidal zone samples were taken at least 100 m from the mangroves to respect the Kulaluk land boundary. It should be noted that this boundary could have some implications for the diversity of species collected (see Discussion).

In the field, at each sample site:

- A line on the Mud Data Sheet was filled out;
- A surface count of visible larger animals was made in a 50 cm^2 quadrat;
- A 100 mm diameter core made of PVC-pipe (see Figure 6) was pushed down to a depth of 20 cm (less if the corer hit a hard layer below in which we expect no benthic animals would be living and it is assumed that shorebirds would also not be able to penetrate). To remove the corer without losing the sample, it was twisted 180 degrees and pulled out slowly at an angle with a thumb placed over the air hole;
- The core was washed on site with seawater through a 1 mm mesh sieve into a bucket;

Table 1. Benthic survey sample sites.

Sample number	GPS Label	Sample label	Latitude (°S)	Longitude (°E)
Example	Lud 1	Lud 1	12.39978	130.84270
1	LudM1	LudM1	12.38856	130.84349
2	LudH1	LudH1	12.38952	130.84544
3	LudL1	LudL1	12.38807	130.84160
4	LudM2	LudM2	12.39512	130.84847
5	LudL2	LudL2	12.39062	130.84041
6	LudH2	LudH2	12.39333	130.84464
7	LudL3	LudL3	12.39370	130.83832
8	LudM3	LudM3	12.39497	130.84135
9	LudH3	LudH3	12.39558	130.84338
10	LudM7	LudM7	12.40480	130.82744
11	LudL6	LudL6	12.40462	130.83179
12	LudM5	LudM5	12.40242	130.83487
13	LudM4	LudM4	12.40080	130.83774
14	LudL4	LudL4	12.39653	130.83459
15	LudL5	LudL5	12.39900	130.83191
16	LudH7	LudH7	12.40524	130.82712
17	LudH6	LudH6	12.40668	130.83124
18	LudM6	LudM6	12.40625	130.83141
19	LudH5	LudH5	12.40589	130.83656
20	LudH4	LudH4	12.40257	130.83966
21	LudL7	LudL7	12.40241	130.82864
EXTRA	wormhole		12.38848	130.84351

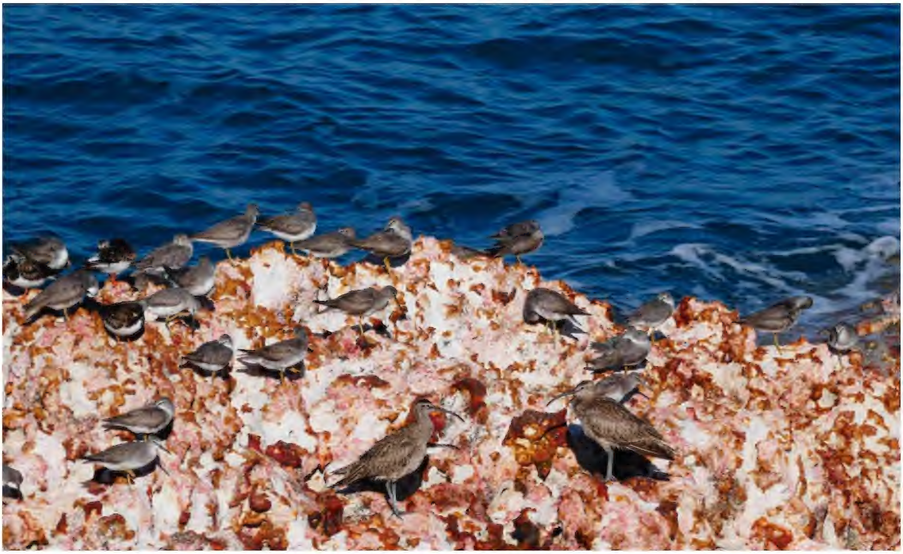


Figure 3. East Point B bird count site. (Anne O'Dea)

- The material remaining on the sieve was washed with sea water into a white tray (to maximise visibility of specimens) with approx. 1 cm deep clear sea water. All visible (2 mm or larger) invertebrates were collected with plastic tweezers and placed in 75% ethanol sample vials. All animals from a single core sample were placed in a single vial;
- A waterproof label indicating the sample site and the date was added to the vial.

For each sample, the composition of the sediment was recorded as Mud (M), Sand (S), Shell (Sh) or Rock (R) in order of greatest to least (e.g. S, M, Sh = Mostly sand, then mud and least shell, no rock).

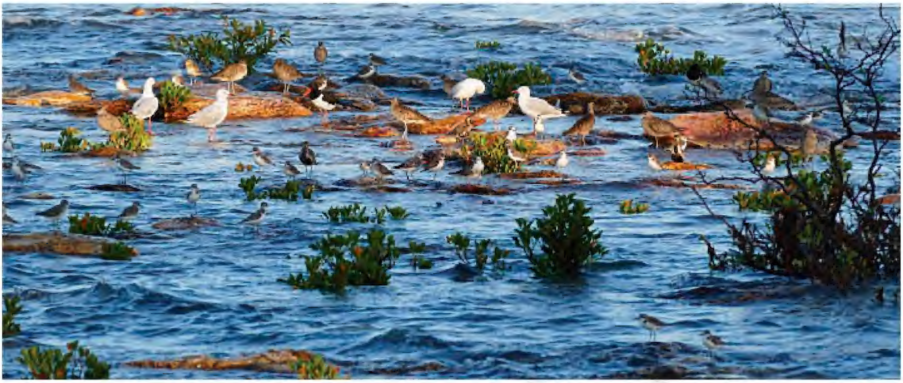


Figure 4. Nightcliff Rocks Site. (Anne O'Dea)

Figure 5. Volunteers and CVA staff monitor shorebirds. (Steve Winderlich)

For each sample site, the permeability of the substrate was recorded as FS = foot sinks, C = core pushed in by hand, H = hammer needed to push core in.

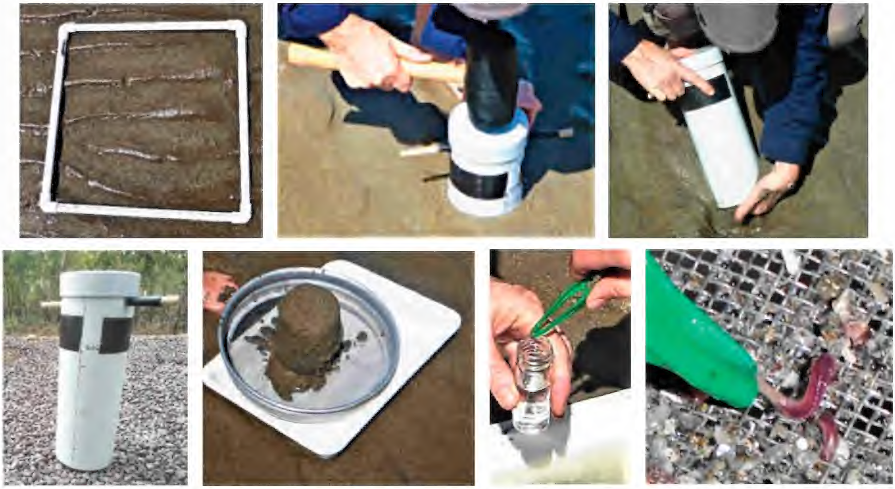


Figure 6. Method for invertebrate sampling. (Steve Winderlich)

The biological samples were taken back to the CVA office and refrigerated. The following day each sample was sorted in a sample tray. The maximum length of long species, or width of wide species was recorded to the nearest 2 mm.

Each animal was photographed using a *Dinolite* portable USB microscope. Ideally, each specimen was photographed on a black and then on a white background, taking care to include the whole animal and achieving fine focus. Each photo was saved into a folder matching the sample site label, and each invertebrate given an individual folder and label, example [LudM7worm1 33 mm]. The photos and samples were used to identify each organism to the lowest possible taxonomic level based on morphological characteristics.

The samples were subsequently given to staff at MAGNT for identification. Following identification, some of the more significant specimens were added to MAGNT's Natural Science collections.

Results

A total of 21 core sample sites were each sampled in August, November and December 2018. While one site was too wet in December, an extra site was sampled in August. A total of 240 invertebrates were recorded from the 63 samples with an average of 3.8 invertebrates found in each sample, including surface species observed in a 50 cm^2 quadrat.

The majority of invertebrate taxa were present at all the samples, but brachiopods (*Lingula anatina*) were found only in the Lud6 samples.

A total of 61 specimen lots of molluscs, seven specimen lots of annelids and two specimen lots of echinoderms from these samples were deemed useful additions to the

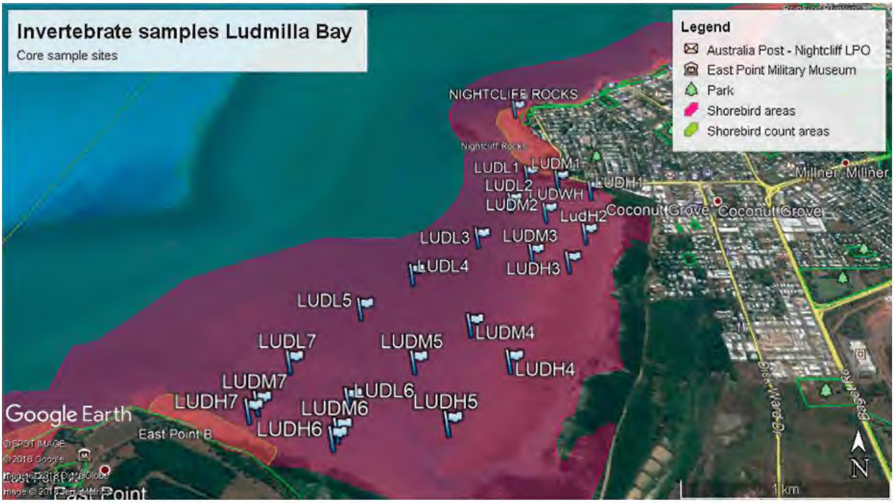


Figure 7. Sampling sites for invertebrates.

MAGNT's Natural Science collections after identification, so they were databased and incorporated into the collections.

Awareness of the value of Ludmilla Bay

All volunteers involved with the project received information about shorebirds, benthic invertebrates and the part Ludmilla Bay plays as a feeding area for resident and migratory shorebirds.

Adrian Williams (Conservation Officer for CVA) attended the Darwin Threatened Species Day event in September 2018 where he highlighted the work of the organisation to protect threatened species. The event included a display. The event also highlighted shorebirds and Adrian spoke to interested visitors about the Ludmilla Bay project to help raise awareness of the environmental value of the Bay

Community involvement in monitoring

Community volunteers contributed 53 days to monitoring for this project, equating to over 400 person hours. This included teams working on the shorebird surveys, collecting and processing the core samples, collating and photographing the specimens from the core

Table 2. Summary of shorebird monitoring results.

Species	**East Point A 30/8/2018**	**East Point A 26/1/2019**	**East Point B 28/8/2018**	**East Point B 26/1/2019**	**Nightcliff rocks 28/8/2018**	**Nightcliff rocks 12/10/2018**	**Spot On Marine 30/8/2018**	**Spot On Marine 19/3/2019**
Notes							Dingoes present	No birds
Total birds	**89**	**186**	**196**	**116**	**104**	**265**	**2**	**0**
No of species	**6**	**12**	**12**	**8**	**13**	**15**	**1**	**0**
Australian Pied Oystercatcher	0	0	0	0	2	2	0	0
Beach Stone-curlew	0	0	2	0	0	0	0	0
Common Sandpiper	0	20	6	4	5	4	2	0
Crested Tern	0	5	2	0	2	5	0	0
Eastern Curlew	0	0	0	0	0	1	0	0
Eastern Reef Egret	0	0	1	0	0	2	0	0
Great Knot	0	3	0	5	1	0	0	0
Greater Sand Plover	2	65	58	22	48	111	0	0
Grey Plover	0	0	0	0	0	12	0	0
Grey-tailed Tattler	65	34	2	23	11	16	0	0
Lesser Sand Plover	0	16	0	14	1	6	0	0
Little Tern	0	2	0	0	0	0	0	0
Masked Lapwing	0	2	8	0	5	2	0	0
Pacific Golden Plover	3	0	2	0	5	0	0	0
Red-necked Stint	0	0	107	0	3	86	0	0
Ruddy Turnstone	14	25	6	19	0	5	0	0
Silver Gull	0	0	1	0	7	2	0	0
Striated Heron	0	1	0	2	0	0	0	0
Terek Sandpiper	0	10	0	8	1	5	0	0
Whimbrel	5	3	0	0	13	6	0	0
Whistling Kite	0	0	1	0	0	0	0	0

samples, and assisting with the display for Threatened Species Day. This highlights the value of organisations such as CVA in continuing to engage in citizen science and make a positive contribution to threatened species understanding and management.

Discussion

Shorebirds

Ludmilla Bay is one of nine Darwin shorebird count areas included

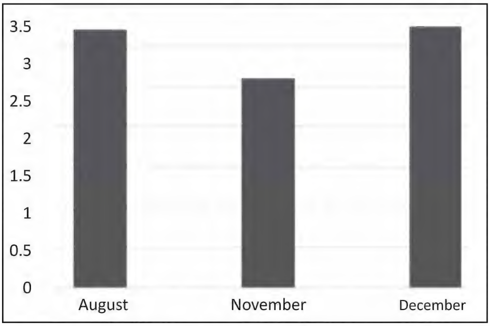
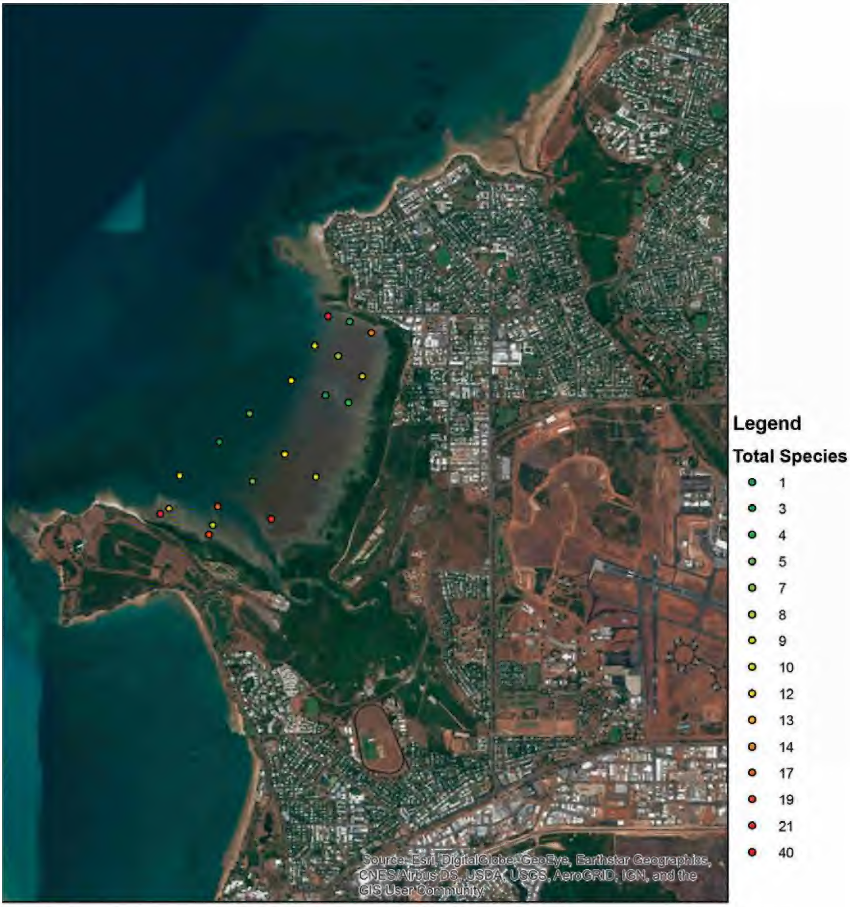


Figure 8. Average number of invertebrates found in samples.



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 9. Population density of invertebrates in Ludmilla Bay. (Map prepared by Darren Kennedy, Conservation Volunteers Australia)

in 'Shorebirds 2020' which is co-ordinated by BirdLife Australia and involves 1600 volunteers at over 460 locations Australia wide. The Darwin areas have been regularly monitored, mainly by interested residents, since 1980 (Weller & Lee 2018), so there are quite a lot of data relating to the shorebirds that frequent the area. Data like this have contributed to protection of the area and some level of public awareness. For example, a Birdlife Migratory Shorebirds sign has been erected at the Nightcliff Rocks site (Figure 12).

Table 3. Summary of core sample substrate and invertebrates.
Permeability: FS = foot sinks, C = core pushed in by hand, H = need hammer.
Composition: Mud (M), Sand (S,) Shell (Sh), Rock (R) in order most to least

Sample number	**Latitude**	**Longitude**	**Composition**	**Permeability FS? C? H?**	**Total all species**	**Surface crustaceans**	**Surface gastropods**	**Total Annelida (segmented worms)**	**Total Mollusca (shellfish)**	**Total Echinodermata (Starfish *et al*)**	**Total Crustacea (crabs *et al*)**	**Total Brachiopoda (lampshells)**	**Total Cnidaria (Anemones *et al*)**	**Total Nemertea (ribbon worms)**
Worm hole	12.38848	130.84351	S, M, Sh	C	5	2	0	2	0	0	1	0	0	0
LudL1	12.38807	130.84160	S, M, Sh	C	21	7	0	3	4	0	7	0	0	0
LudM1	12.38856	130.84349	S, M, Sh	C	4	0	0	3	0	0	1	0	0	0
LudH1	12.38952	130.84544	S, M, Sh	C	14	0	0	2	1	0	11	0	0	0
LudL2	12.39062	130.84041	S, M, Sh	C	10	1	0	3	4	1	1	0	0	0
LudM2	12.39512	130.84847	S, M, Sh	C	7	0	0	4	1	2	0	0	0	0
LudH2	12.39333	130.84464	S, M, Sh	C	8	0	0	6	0	0	2	0	0	0
LudL3	12.39370	130.83832	S, M, Sh	C	10	5	0	1	1	0	3	0	0	0
LudM3	12.39497	130.84135	S, M, Sh	C	3	0	0	0	0	0	3	0	0	0
LudH3	12.39558	130.84338	S, M, Sh	C	4	0	0	1	0	0	2	0	1	0
LudL4	12.39653	130.83459	S, M, Sh	C	5	1	0	2	1	0	1	0	0	0
LudM4	12.40080	130.83774	S, M, Sh	C	12	0	0	8	0	2	2	0	0	0
LudH4	12.40257	130.83966	S, M, Sh	C	9	1	0	3	1	0	4	0	0	0
LudL5	12.39900	130.83191	S, M, Sh	C	1	0	0	0	0	0	1	0	0	0
LudM5	12.40242	130.83487	S, M, Sh	FS	5	1	0	1	1	0	1	0	0	1
LudH5	12.40589	130.83656	S, M, Sh	C	21	5	0	3	1	7	5	0	0	0
LudL6	12.40462	130.83179	S, M, Sh	C	17	1	0	2	0	0	1	13	0	0
LudM6	12.40625	130.83141	S,M,Sh,R	C 20mm	8	0	0	3	1	0	2	2	0	0
LudH6	12.40668	130.83124	S,M,Sh,R	C 50mm	19	4	1	8	0	1	1	4	0	0
LudL7	12.40241	130.82864	S, M, Sh	C	9	0	0	5	3	0	1	0	0	0
LudM7	12.40480	130.82744	M, S, Sh	C 80mm	13	0	0	1	0	0	12	0	0	0
LudH7	12.40524	130.82712	M, S, Sh	C	40	12	4	4	2	0	18	0	0	0

Table 4. Summary of invertebrate species found in Ludmilla Bay samples. Note that a question mark denotes identifications that were not confirmed.

Class/phylum	Family/order	Genus/species	Common name or description	No. found	Month	Av size (mm)	Range (mm)	Suitability for shorebird food
Annelida	Spionidae	*Scolelepis* sp.		2	Aug	11	8 to 13	
Annelida	Spionidae	*Scolelepis* sp.		1	Dec			
Annelida	Glyceridae	*Glycera nicobarica*	Predatory worm	4	Aug	19	9 to 33	
Annelida	Glyceridae	*Glycera nicobarica*		1	Nov			
Annelida	Glyceridae	*Glycera nicobarica*		2	Dec			
Annelida	Opheliidae	*Armandia* cf. *longicaudata*		5	Aug	10	4 to 16	
Annelida	Opheliidae	*Armandia* cf. *longicaudata*		1	Dec			Unlikely
Annelida	Chaetopteridae		Plastic worm	2	Aug	19	18 to 19	
Annelida	Onuphidae	*Onuphis* sp.	Beachworms	2	Aug	16	11 to 21	Likely
Annelida	Orbiniidae			1	Aug	30	30	
Annelida	Capitellidae	*Notomastus* sp.	Reddish worms	1	Aug	>15	>15	
Annelida	Capitellidae	Sp.	Reddish worms	1	Aug	>6	>6	
Annelida	Nephtyidae	*Nephtys* sp.	Catworm	5	Aug	11	4 to23	
Annelida	Nephtyidae	*Nephtys* sp.	Catworm	2	Nov			Unlikely
Annelida	Nephtyidae	*Nephtys* sp.	Catworm	3	Dec			Unlikely
Annelida	Maldanidae	*Axiothella* sp.	Bamboo worm	8	Aug	24	4 to 146	Unlikely
Annelida	Maldanidae	*Axiothella* sp.	Bamboo worm	8	Nov			
Annelida	Maldanidae	*Axiothella* sp.	Bamboo worm	3	Dec			
Annelida	Terebellidae		Large tube building worm	1	Aug	>55	>55	
Annelida	Phyllodocidae	*Phyllodoce* sp.	Train worm	1	Aug	>43	>43	Unlikely?
Annelida	Phyllodocidae	*Phyllodoce* sp.	Train worm	1	Nov			Unlikely?
Annelida	Pillargidae?			1	Aug	12	12	
Annelida	Nereididae	*Simplisetia* sp.		1	Aug	38	38	
Annelida	Cirratulidae	*Chaetozone* sp.	Cylindrical worm	1	Aug	13	13	
Annelida	Oweniidae		Bristleworm	1	Nov	4		
Annelida	Oweniidae	*Owenia mirrawa*	Bristleworm	2	Dec	70	16 to 123	Unlikely
Annelida	Unidentified			5	Nov	20	2 to 38	
Mollusca	Columbellidae	*Mitrella essingtonensis*	Gastropod (snail)	1	Aug	9	5 to 13	Unlikely
Mollusca	Columbellidae	*Mitrella essingtonensis*	Gastropod (snail)	3	Nov			Possibly if 3-5mm
Mollusca	Columbellidae	*Mitrella essingtonensis*	Gastropod (snail)	7	Dec			Possibly if 3-5mm
Mollusca	Terebridae	*Euterebra tantilla*	Gastropod (snail)	1	Aug	4	2 to 5	Possibly if 3-5mm

Continued on next page.

Table 4. Summary of invertebrate species found in Ludmilla Bay samples. Note that a question mark denotes identifications that were not confirmed. (Continued from previous page.)

Class/phylum	Family/order	Genus/species	Common name or description	No. found	Month	Av size (mm)	Range (mm)	Suitability for shorebird food
Mollusca	Terebridae	*Euterebra tantilla*	Gastropod (snail)	1	Nov			Possibly if 3-5mm
Mollusca	Terebridae	*Euterebra tantilla*	Gastropod (snail)	2	Dec			Possibly if 3-5mm
Mollusca	Pyramidellidae	*Turbonilla* sp.	Gastropod (snail)	1	Nov	8	8	Possibly if 3-5mm
Mollusca	Mactridae	*Mactra abbreviata*	Bivalve (clam)	1	Dec	9	9	Possibly if 3-5mm
Mollusca	Dentaliidae	*Dentalium austini*	Tusk shell	1	Dec	12	12	Likely
Mollusca	Veneridae	*Dosinia laminata*	Bivalve (clam)	1	Dec	3	3	
Echinodermata	Arachnoididae	*Arachnoides placenta*	Sand dollar	2	Aug	14	8 to 19	Likely
Echinodermata	Arachnoididae	*Arachnoides placenta*	Sand dollar	5	Dec			Possibly (eg. turnstones)
Echinodermata	Ophioroidae		Brittle star	1	Nov	35	12 to 68	Possibly (eg. turnstones)
Echinodermata	Ophioroidae		Brittle star	2	Dec			Possibly
Echinodermata	Holothurian?		Sea cucumber	2	Nov	45	8 to 114	Possibly
Echinodermata	Holothurian		Sea cucumber	1	Dec			Possibly
Crustacea	Matutidae	*Matuta* sp.	Burrowing sand crab	1	Aug	7	5 to 9	Likely
Crustacea	Matutidae	*Matuta* sp.	Burrowing sand crab	1	Dec			Likely
Crustacea	Diogenidae		Hermit crab	15	Aug	7	2 to 18	Possibly Gt knot obs esp 3-5mm
Crustacea	Diogenidae		Hermit crab	23	Nov			Possibly
Crustacea	Diogenidae		Hermit crab	27	Dec			Possibly
Crustacea	Mysidacea		Shrimp	1	Aug	7	7	Likely
Crustacea	Myctyridae	*Mictryis darwinensis*	Soldier crab	1	Aug	23	23	Likely
Crustacea	Amphipoda		Sand hopper	5	Aug	5	2 to 18	Likely
Crustacea	Amphipoda		Sand hopper	2	Dec			Likely
Cnidaria	Ceriantharia sp?		Burrowing sea anemone	1	Aug	9	9	
Brachiopoda	Lingulidae	*Lingula anatina*	Burrowing lampshell	2	Aug	15	6 to 23	Likely
Brachiopoda	Lingulidae	*Lingula anatina*	Burrowing lampshell	4	Nov			Likely
Brachiopoda	Lingulidae	*Lingula anatina*	Burrowing lampshell	13	Dec			Likely
Nemertea			Ribbon (unsegmented) worm	1	Aug	>11	>11	

Figure 10. A selection of the invertebrate specimens present in the samples. **A.** *Glycera nicobarica* (Annelida: Glyceridae). **B.** Sand hopper (Crustacea: Amphipoda). **C.** Mysid shrimp (Crustacea: Mysidacea). **D.** Hermit crab (Crustacea: Diogenidae) in a *Nassarius fraudator* shell. **E.** *Isanda coronata* (Mollusca: Trochidae), a mollusc whose shell is commonly used by hermit crabs. **F.** Box crab (*Matuta* sp.) (Crustacea: Matutidae). **G.** Soldier crab (*Mictryis darwinensis*) (Crustacea: Mictryidae). **H.** Lampshell (*Lingula anatina*) (Brachiopoda: Lingulidae).

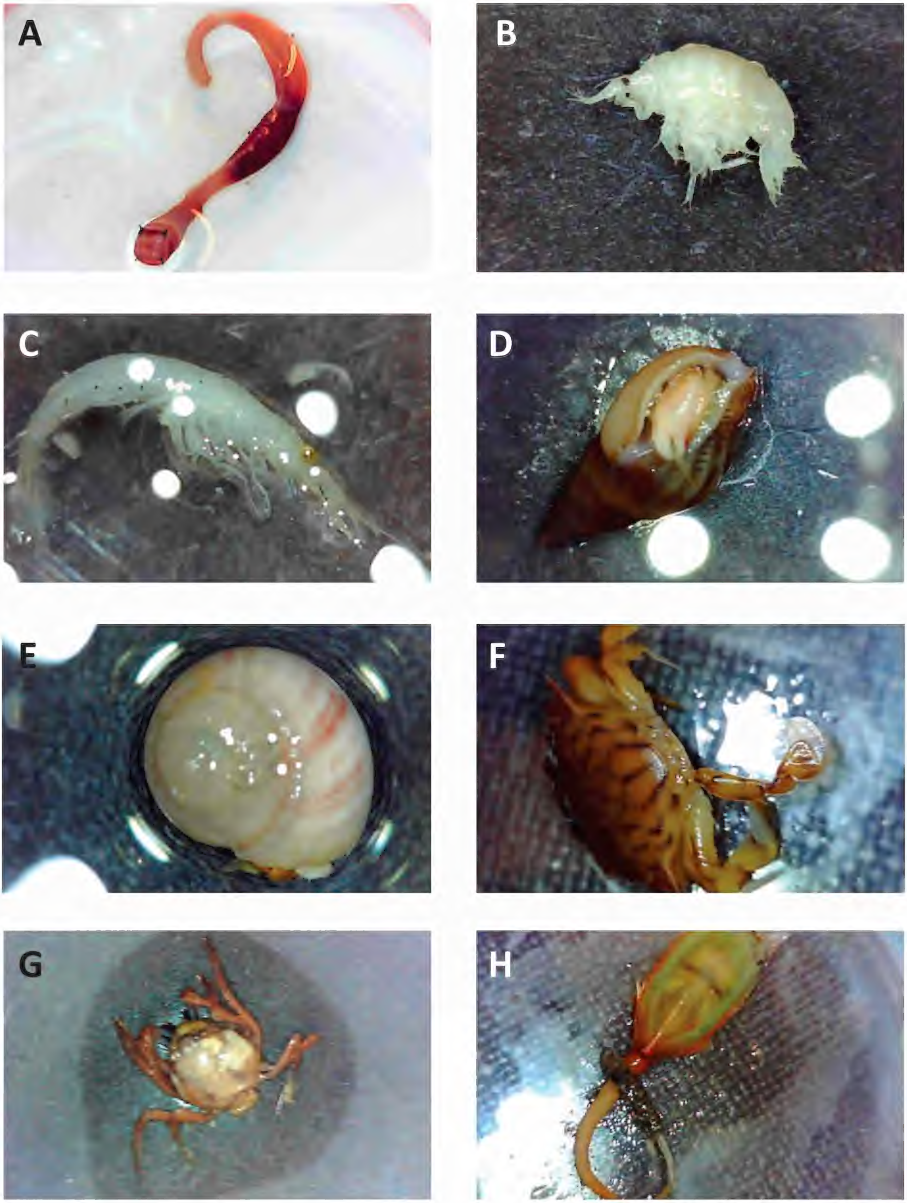


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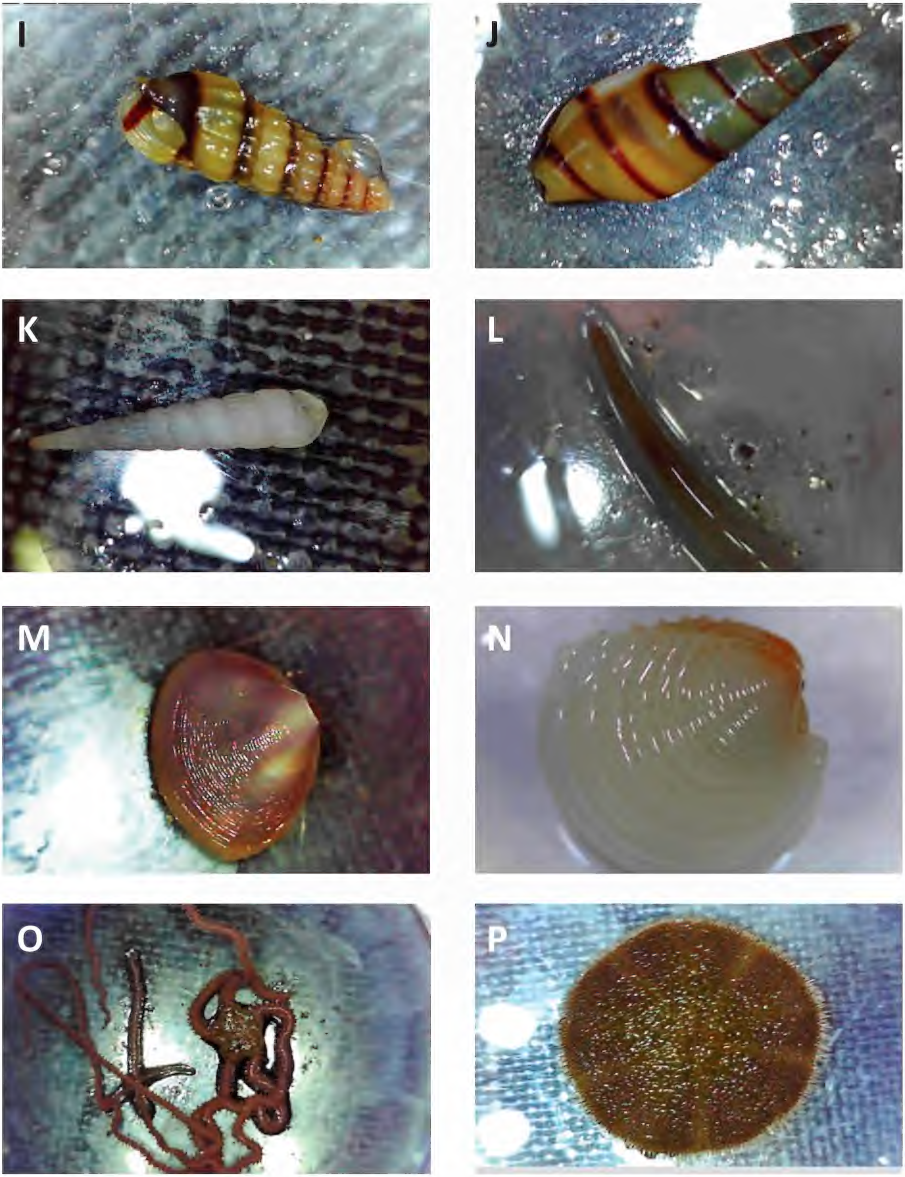
Figure 10. A selection of the invertebrate specimens present in the samples. (Continued from previous page.) **I.** Live auger snail *Euterebra tantilla* (Mollusca: Terebridae). **J.** Dove snail *Mitrella essingtonensis* (Mollusca: Columbellidae). **K.** Small parasitic snail (*Turbonilla sp.*) (Mollusca: Pyramidellidae). **L.** Tusk shell (*Dentalium austini*) (Mollusca: Dentaliidae). **M.** Juvenile trough clam (*Mactra abbreviata*) (Mollusca: Mactridae). **N.** Juvenile biscuit clam (*Dosinia laminata*) (Mollusca: Veneridae). **O.** Brittle star (Echinodermata: Ophiuridae). **P.** Sand dollar (*Arachnoides placenta*) (Echinodermata: Arachnoidae)



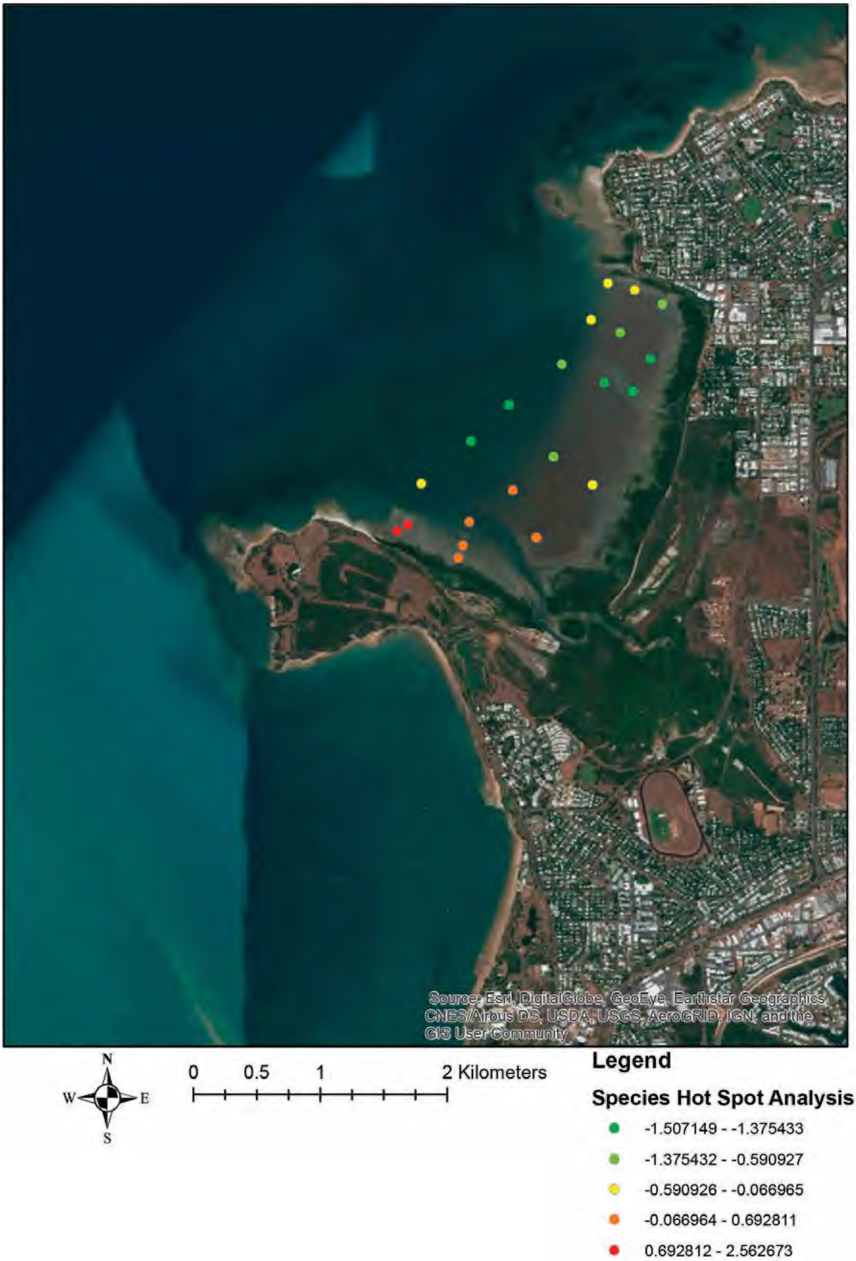

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 11. Invertebrate diversity across Ludmilla Bay. (Map prepared by Darren Kennedy, Conservation Volunteers Australia)

Table 5. Gastropod shells used by hermit crabs.

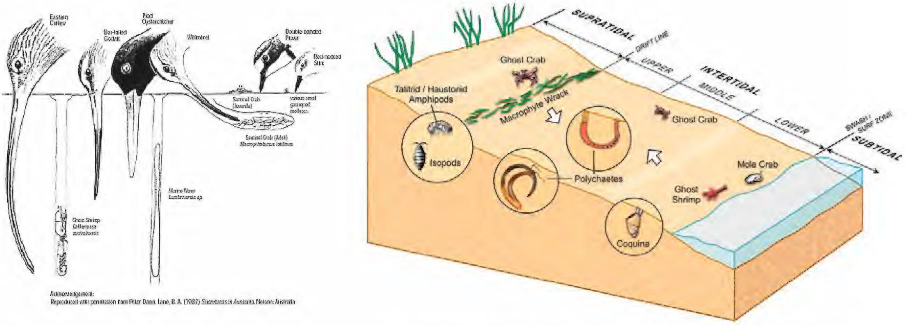
Hermit crab 'home' shells	
Total	69
Isanda coronata	21
Mitrella essingtonensis	3
Pirenella delicatula	23
Euterebra tantilla	3
Clypeomorus batillariaeformis	14
Neverita didyma	1
Nassarius fraudator	1
Pupa cf. *affinis*	1
Monilea callifera	1
Vexillum vulpecula	1

Figure 12. Migratory shorebird sign at Nightcliff Rocks. (Anne O'Dea)

Results of the shorebird counts showed an increase in birds between August and the period of October to January. This is to be expected as the migratory birds swell in numbers as they arrive in Australian sites around this time from the Northern Hemisphere.

There were not many birds recorded on the Spot On Marine clay-pan, but the site is worth checking as the shorebirds can be pushed up there during very high tides (John Rawsthorne pers. comm.).

Individual shorebirds can use several feeding and roosting sites within the North Darwin shorebird area at different times. As there were limited trained shorebird surveyors, and an emphasis of the program was to raise awareness of the shorebirds by interested participants, the counts were not all made concurrently, so it is possible that some birds were counted twice or missed due to this movement. However, this is not considered to have had a significant impact on the results.



Acknowledgement:
Reproduced with permission from Peter Dann. Lane, B. A. (1987) *Shorebirds in Australia*. Nelson: Australia

From Lane, B. Shorebirds in Australia, 1987

From Michel *et al.* Oil spill response-related injuries on sand beaches: When shoreline treatment extends the impacts beyond the oil, 2017.

Figure 13. Examples of information supplied to volunteers to raise awareness of shorebirds and invertebrates.

Few disturbances were recorded for the shorebirds during the days of the 'Shorebirds 2020' censuses, but on other days around the same time some disturbing influences were noted. These included people fishing off the highest rock at the end of the Nightcliff rocky spit, boats moving through the Nightcliff area, and people walking down the steps to access the Nightcliff rocky platform which acts as a high tide roost for the birds. John Rawsthorne commented that, in his experience, these disturbances are common. There was less disturbance at East Point where the roosts are less accessible.

Site

Clearly Ludmilla Bay is suitable for shorebirds. This requires the area to have a suitable substrate and enough food. At each sample site, the permeability of the substrate was recorded to gauge whether it is likely to be suitable for the shorebirds that push their bills into the mud. Eastern Curlews, for example, prefer substrates with lower resistance where prey is more available to them. Thus, substrate type can be more important than prey density (Saint-Béat 2013). Most of the area was found to be muddy sand with shell grit. At all sites it was easy to push the corer into the mud by hand, although near the East Point end of the Bay there were three sample sites where there was rock under and in the mud, making it impossible to push the corer to the standard depth of 20 cm. These correspond to areas where there were more crustaceans on the surface, making these areas more suitable for shorter-billed shorebirds such as plovers. LudM5 site was the only site recorded as very soft so that the feet of the survey team sank into the mud.

General observations on invertebrates

For an invertebrate, the likelihood of being eaten by a shorebird is not well researched, but Piersma *et al.* (2018) outlined several factors believed to contribute to the suitability of an invertebrate to be taken as food by a shorebird. Using the information in their report, notes are made against each species in Table 4 about whether the species is likely to be suitable shorebird food. Most species are seen to be suitable food for shorebirds. For gastropods and hermit crabs, Piersma *et al.* (2018) discuss that only small animals (3–5 mm) are likely to be suitable shorebird food.

Invertebrate samples were taken from 21 sites spread across Ludmilla Bay and from low to high tide. While this is a relatively small sample size, some observations can be made.

The survey area commenced 100 m seaward of the mangrove line for the cultural reasons explained above. This does mean that a significant area relevant to this project was not sampled as some important food species only occur in this zone; for example, the small clam *Paphies altenai* can be very common on intertidal sandflats (Richard Willan pers. comm.). Therefore, it would be advantageous to include this area in future surveys with permission from Traditional Owners.

The 21 core sample sites were each sampled in August, November and December. While one site was too wet in December, an extra site was sampled in August. A total of 240 individual invertebrates were recorded from the 63 samples with an average of

3.8 invertebrates found in each sample, including surface species observed in a 50 cm quadrat. Hermit crab numbers were quite high in these higher density areas, boosting the crustacean numbers.

The number of invertebrates found in samples was similar in August, November and December. A much greater number of samples would be needed to pick up any significant change in samples over the year.

It is advisable to take photos on both black and white backgrounds to ensure the best quality images for identification. Photographs taken on a black background were generally better than those taken on a white background, but for a few specimens the white background photos were better.

Some of the specimens were smaller or juvenile in form. These smaller individuals are harder to identify as they can be different, or lack some of the adult traits usually described (Peter Hunt pers. comm.).

Many of the annelid worm specimens had been broken into fragments during the collection process. Table 4 shows the average and range of size recorded of each species. Sizes of specimens considered to be fragments were added together, and where some of the worm was completely missing ">" was used to denote that the specimen was greater than the size recorded.

A not inconsiderable number of the gastropod shells collected during the surveys were inhabited by hermit crabs. Some of these were not recognised as crustaceans rather than molluscs at the time of sorting from empty shells. Richard Willan separated the live-taken molluscs from the shells which probably had hermit crabs inside them at time of collection. The shells deemed to probably have hermit crabs were recorded as hermit crabs and the variety of shells used as hermit crab 'homes' is listed in Table 5. The 69 hermit crabs collected used 11 different gastropod species shells, with most using those of *Pirenella delicatula* or *Isanda coronata*.

Population density

As shown on the population density map (Figure 9), the density of invertebrates over all sampling events was greatest around the creek at the East Point end of Ludmilla Bay and a smaller area at the Nightcliff end of the Bay. This included surface species, mainly represented by hermit crabs. There were also a lot of Soldier Crabs (*Mictryis darwinensis*) around the creek area, but only one buried individual was recorded in the samples as they tended to be long-buried when samplers approached the area.

Brachiopods were only found in the Lud6 sites where there was a small area of high density of one infaunal species (*Lingula anatina*).

Biodiversity

A total of 17 taxa of annelids (segmented worms), 6 molluscs (shellfish), 5 crustaceans (crabs *et al.*), 3 echinoderms (starfish *et al.*), 1 cnidarian (sea anemone), 1 brachiopod (lampshell) and 1 nemertean (ribbon worm) was recorded, making a total of 34 taxa identified from 63 samples at 21 sites. The low number of samples makes it difficult to compare the diversity and number of invertebrates at Ludmilla Bay with other sites, but the number of shorebirds using the area and the data developed in this relatively small study, support the diversity and importance of the area as a valuable habitat for the birds.

Hotspot analysis of the data (Figure 10) shows that the invertebrate diversity was higher at either end of the Bay, particularly around East Point where the creek outflow probably adds to nutrient availability. There is also a sewerage outfall in that area, but no samples were taken in the area shown as affected by that outfall.

With further sampling and analysis it would be possible to create a clearer picture of the biodiversity and if there is any difference over the year as has been observed in other places (Saint-Béat 2013).

Conclusion

Ludmilla Bay and the entire North Darwin Shorebird Areas are recognised as valuable habitat for shorebirds. However, shorebirds are susceptible to disturbance that makes them waste energy needed for their long migratory flights (Weller & Lee 2018).

Clearly, the benthic invertebrate fauna is currently sufficient to support the hundreds of shorebirds that feed in Ludmilla Bay in particular, and also the larger population that feeds in the entire North Darwin area. However, there is little known about the invertebrate fauna, its place in the food web and potential impacts. By improving knowledge of these species, their conservation needs can be better understood in a changing climate (Baker *et al.* 2015) and in the event of any proposed development for the area.

This project gave a snapshot of the invertebrates that shorebirds rely on as food in Ludmilla Bay, but further research would be required to gain a clearer picture for Darwin Harbour as a whole. It would also be valuable to locate the results of previous sampling in the North Darwin Shorebird Area to increase the information and gain a more comprehensive picture of any change over time.

Community engagement like that involved with this program is critical. It provides the labour to get the job done and at the same time it raises community awareness, particularly among users of the public sites along the North Darwin Shorebird Area. Activities like this will hopefully help people to understand the importance of the Area to shorebirds and the need to prevent disturbance to ensure the shorebirds conserve valuable energy gained from the mudflat banquets so that they can accomplish their long journey. There is great potential to provide community awareness of this fascinating ecological story of the relationship between shorebirds and the benthic invertebrates.

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A population of the rare Northern Shrike-tit that forages and breeds in a seasonally inundated paperbark woodland in Arnhem Land, Northern Territory

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Abstract

The vast majority of records of the Northern Shrike-tit (*Falcunculus whitei*) in the Top End of the Northern Territory are from eucalypt woodlands in inland localities, mostly in the Katherine-Maranboy region, approx. 250 km from the nearest coastline. This report summarises observations of a small resident population of these rare birds which is largely confined to a paperbark woodland on the seasonally inundated floodplain of the Tomkinson River, a tributary of the Liverpool River, only 17–35 km from the coast of western Arnhem Land. The population is apparently isolated and small (8–50 pairs) with a relatively low density (est. 0.01 birds ha^{-1}), and given its existence since at least 2000, appears sustainable. These birds forage mainly on Broad-leaved Paperbark (*Melaleuca viridiflora*), in which they obtain arthropod prey from both leaves and bark. Nest-building was observed in September and October, and dependent juveniles were present in two territories in early March. One nest was built in a paperbark tree, the lowest nest height (6.5 m) reported for the species to date and the first in a non-eucalypt. Vocalisations of birds in this population differed from those described and recorded in the literature for the species. Although it has been argued that the scarcity of this species in northern Australia is due to the paucity of eucalypt species that shed their bark annually, both the Tomkinson River population and some populations of the species' two congeners forage partly, or even largely, on foliage.

Introduction

Patchily distributed within the Top End of the Northern Territory and the Kimberley region of Western Australia, the rare Northern Shrike-tit (*Falcunculus whitei*) (Figure 1) differs slightly in appearance from the commoner Eastern Shrike-tit (*F. frontatus*) in being smaller with a relatively larger bill, and in having more white on its face and yellowish (instead of grey) edges to its wing feathers (Franklin *et al.* 1997; Higgins & Peter 2002; Menkhorst *et al.* 2017), as well as in its song (Rix 1970). Formerly listed as Endangered (Garnett & Crowley 2000; Higgins & Peter 2002), based on the paucity of records and

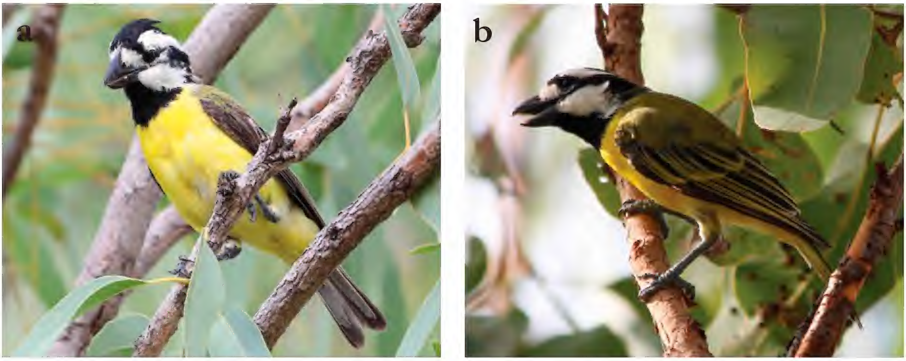

Figure 1 (a, b). Northern Shrike-tit, male, Central Arnhem Road, 9 February 2020. (Marc Gardner)

information on its ecological requirements, this bird is now classified as Near-threatened in the Northern Territory (Woinarski & Ward 2012), though it is not listed as Threatened in Western Australia. Nevertheless, it is arguably one of the rarest and most patchily-distributed resident bird species in the Top End. In this paper I follow BirdLife Australia (2020) in treating the taxon as a full species.

The first specimens of the Northern Shrike-tit were collected in the northwestern Kimberley in 1910 by Gerald Hill (Hill 1911), while obtaining specimens for the eminent grazier and natural historian H.L. White, in whose honour the bird had been named *Falcunculus whitei* a year earlier by Campbell (1910). Only three years later it was discovered in the Northern Territory at Borroloola Station on the McArthur River in the southeastern corner of the Top End. Somewhat ironically, although Hill had been stationed there for six months during 1911–1912, it was Henry (Harry) Barnard who found the species at Borroloola and collected a specimen in June 1913, and its nest and eggs in January 2014 (Barnard 1914; White 1914; LeCroy 2010). Remarkably however, the species has not been seen since in the region or anywhere nearby, despite numerous surveys in the McArthur River area (Robinson & Woinarski 1992). It was not until 1944 that the species was recorded in the Top End again; this time by English-born Eric Sedgwick (Sedgwick 1947) while serving with the Royal Australian Air Force during WW II, and its location was Larrimah, approx. 335 km WNW of Borroloola and approx. 250 km SSW of the nearest coast of the Gulf of Carpentaria. Since then, most sightings of this species have been concentrated in the region between Pine Creek, Maranboy and Mataranka (Rix 1970; Holmes & Noske 1990; Robinson & Woinarski 1992; Franklin *et al.* 1997; McCrie & Watson 2003).

The habitat and foraging behaviour of the Northern Shrike-tit were reviewed by Robinson & Woinarski (1992), who showed that the vast majority of records known at the time were from eucalypt woodlands, especially those dominated by Darwin Stringybark (*Eucalyptus tetradonta*), Darwin Woollybutt (*E. miniata*) and Shiny-leaved Bloodwood (*Corymbia bleeseri*). The scant information on its foraging behaviour and diet suggests that, like its southeastern counterpart, it prises or tears bark from living or dead eucalypts (Sedgwick 1947; Robinson *et al.* 1992; Robinson & Woinarski 1992) and hunts among dead leaves (Barnard 1914) in search of insects and spiders. All nests found to date have been in eucalypts (Barnard 1914; Ward *et al.* 2009). In this paper, I provide details of the habitat, foraging behaviour, breeding season and vocalisations of a population of Northern Shrike-tits that live on a seasonally inundated floodplain in sub-coastal western Arnhem Land.

Study area and historical background

Much of the eastern half of the Top End lies within Arnhem Land, which is managed by the Indigenous traditional owners. Access to Arnhem Land requires permits from the Northern Land Council, and, as such, it is rarely visited by ornithologists or birdwatchers (Noske 2017). Until the present century, bird specimen collections and surveys had been restricted to Cobourg Peninsula, in the extreme northwest of Arnhem Land, during the 1840s and 1960s (Frith & Hitchcock 1974; Fisher & Calaby 2009), to King River in 1915–1916 (White 1917a,b), Gunbalanya (formerly Oenpelli) in 1948 and 1968 (Deignan 1964; Hall 1974), and to Gove Peninsula in the 1940s (Humphries 1947; Deignan 1964), in 1974 (Boekel 1976), and in 1998–2000 (Brady & Noske 2010). Significantly, Shrike-tits were not recorded in any of these localities.

The first record of Northern Shrike-tits in northern Arnhem Land was of a pair in eucalypt woodland 35 km south of Ramingining on 6 August 1990 (Robinson e*t al.* 1992; ALA 2020: catalogue no. 1131353). Ten years later, while conducting bird surveys in Arnhem Land for the second national *Atlas of Australian Birds* (Barrett *et al.* 2003), I was attracted to an unfamiliar call at a site approx. 15 km east of Mumeka outstation and the Mann River crossing along the road from Gunbalanya to Maningrida, on 27 September 2000. This area was not revisited until October 2008 when I was leading a 'Bird Week' tour from the Arnhem Land Barramundi Nature Lodge, 17 km SSE of Maningrida. During the following two years, similar tours of 5–7 days were undertaken in June and September 2009, and June–July 2010. All the tours included a vehicular trip or walk to Nangak floodplain lying between the Tomkinson River and the rocky escarpment on which Arnhem Land Barramundi Nature Lodge and Djinkarr Ranger Station (1.7 km south of ABNL) are perched.

In addition to co-leading these bird tours with colleagues Johnny Estbergs and Dick Eussen, I conducted 20 min censuses of 17–19 x 2 ha plots within 20 km of the Arnhem Land Barramundi Nature Lodge in each of six months (October 2008, January, May, August and December 2009, and March 2010). This study compared the avifauna of two distinct local habitats: (1) open eucalypt forest dominated by Darwin Wollybutt and/or Darwin Stringybark, on the rocky plateau (60–80 m asl; n = 8 sites) situated 0.5–12 km from ABNL, and (2) open paperbark woodland dominated by Broad-leaved Paperbark (*Melaleuca viridiflora*) on the seasonally-inundated floodplain (4–40 m asl; n = 9 sites) on the abovementioned Gunbalanya-Maningrida Road, between Mumeka in the west and the turnoff to Ramingining in the east. All but two of the nine paperbark woodland sites were located along a 10 km span of this road, stretching between 15 and 25 km from Mumeka to the Kolorbidahbidah turnoff, 6.5 km south of the Ramingining turnoff, and hereafter referred to as the Upper Tomkinson floodplain (Figure 2). Two additional lower elevation sites differed from the other sites in not being dominated by paperbarks or eucalypts of the abovementioned two species, and were classified as 'mixed woodland' (Figure 3). All the plots were normally sampled three times over 2–3 consecutive days except in January, when four of the paperbark plots could not be accessed due to flooding of the road, and December, when only

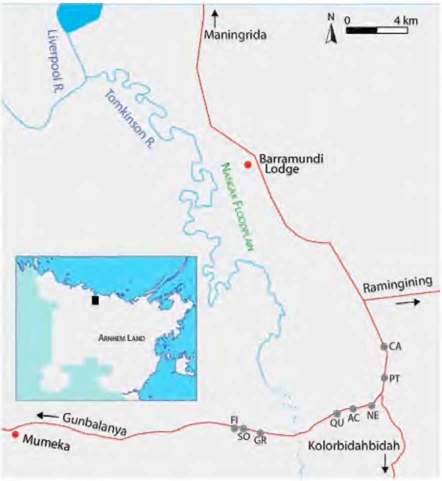

Figure 2. Map of study area, showing location of sites mentioned in Tables 1 and 2 and the text. The inset indicates the area's location within Arnhem Land. (Niven McCrie)

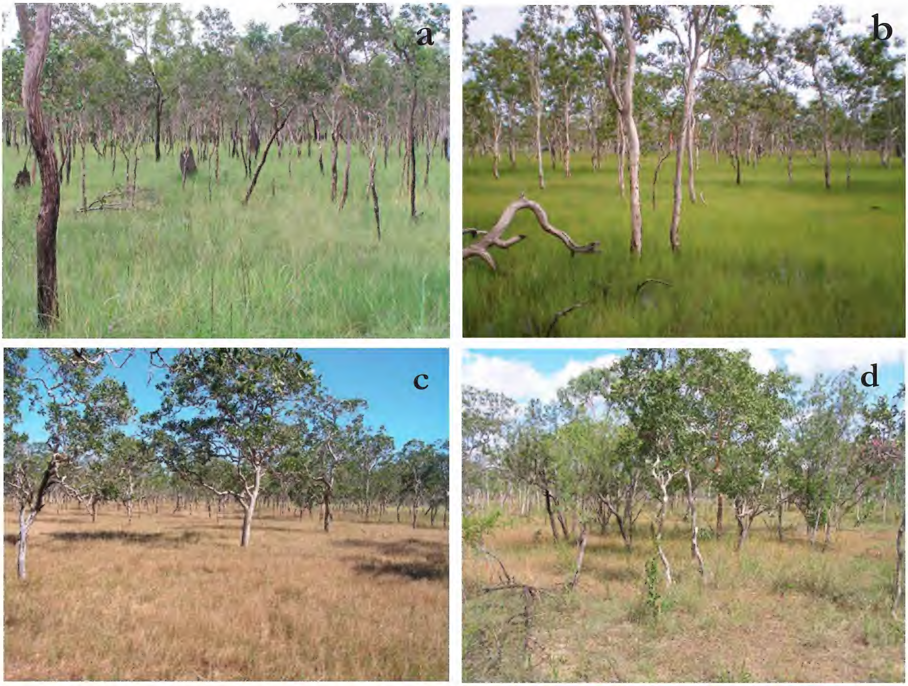

Figure 3. Paperbark woodland habitat in: **a.** January 2009 (Nangak), **b.** March 2010 (Site SD) (surface water present), **c.** May 2009 (Site FI) and **d.** mixed woodland habitat in May 2009 (Site CA). The sites are described in Table 1. (Richard Noske)

paperbark sites were sampled, and only once due to inclement weather. Detailed results of that study will be presented elsewhere. Shrike-tits were located by listening for their vocalisations, sometimes after playing recordings of their calls on an MP3 player.

Results

Shrike-tits were recorded during 25 censuses overall, involving eight sites, six of which were in paperbark woodland (n=124) and two in mixed woodland (n=27 censuses), all at elevations below 40 m asl (Table 1). They were not recorded at any of the eight sites in eucalypt forest on the plateau (n=98), where the trees were typically 17–20 m high, most with an understory of Sand Palms (*Livistona humilis*) and several *Acacia* species. The six paperbark woodland sites were dominated by Broad-leaved Paperbark, typically 5–9 m high, with scattered Round-leaved Bloodwood (*Corymbia latifolia*) and/or Hills Salmon Gum (*E. tintinnans*), 9–12 m high, small patches of Coastal Paperbark (*M. acacioides*), 3–5 m high and a ground cover of grasses including *Eriachne burkettii, Pseudopogonatherum contortum, P. irritans* and *Heterachne gulliveri*. Of the two mixed woodland sites, one was in a poorly-drained area of open woodland comprising a mixture of Long-fruited Bloodwood (*Corymbia polycarpa*) and Swamp Box (*Lophostemon lactifluus*), with scattered Broad-leaved Paperbark, and other species (e.g. *Grevillea pteridifolia*). The other mixed woodland site was in open eucalypt woodland on a well-drained, low, rocky hillside situated between two paperbark woodland sites, and was dominated by scattered Round-leaved Bloodwood and Darwin Stringybark, with groves of Quinine Tree (*Petalostigma pubescens*) and scattered Cooktown Ironwood (*Erythrophleum chlorostachys*) (Table 1).

About half (13) of all records of Shrike-tits during the censuses were from two sites (AC and NE), where birds were encountered on 50% and 38% of censuses, respectively

Table 1. Characteristics of the eight census sites where Northern Shrike-tits were found, and the number of censuses in which they were recorded. Total number of censuses in brackets. Note that "KT*" stands for the Kolorbidahbidah turnoff and the symbols in the last column stand for the following plants: Al, *Acacia leptocarpa;* As, *Asteromyrtus symphiocarpa;* Ce, *Calytrix exstipulata;* Cl, *Corymbia latifolia,* Cp, *C. polycarpa;* Ei, *Eucalyptus tintinnans;* Et, *E. tetradonta;* Gp, *Grevillea pteridifolia,* Ll, *Lophostemon lactifluus;* Ma, *Melaleuca acacioides;* Pp, *Petalostigma pubescens;* Rc, *Erythrophleum chlorostachys.*

Site code	**Distance (km) from KT***	**Woodland type**	**Elevation (m asl)**	**No. censuses recorded (n)**	**Estimated %** *M. viridiflora*	**Other plant species present**
CA	3.4 N	Paperbark	33	1 (13)	60	Cl, Ce, As
PT	1.2 N	Mixed	31	2 (13)	10	Cp, Ll, Gp,
NE	1 W	Paperbark	20	6 (16)	85	Cl, Al
AC	2.3 W	Paperbark	13	7 (14)	75	Cl, Ei, Gp, Al
QU	3.4 W	Mixed	10	2 (14)	30	Pp, Cl, Et, Rc
GR	9 W	Paperbark	5	3 (13)	75	Ma, Gp, Al
SO	10 W	Paperbark	6	1 (14)	90	Ma, Al
FI	11 W	Paperbark	5	3 (14)	95	Al, Ma

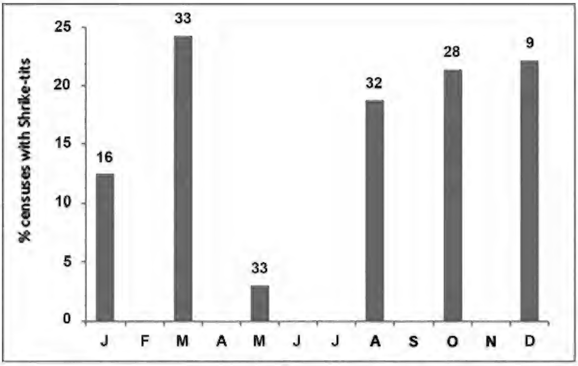

Figure 4. Percentage of censuses on which Northern Shrike-tits were encountered on paperbark and mixed woodland sites. Number of censuses shown above each bar (total number = 151).

(Table 1). Shrike-tits were recorded in each of the three Dry season and three Wet season months sampled, but were least frequently encountered in May (Figure 4). Relative frequencies for January and December may be under-represented or over-represented due to sampling biases caused by rain and flooding, respectively. In addition, Shrike-tits were observed on Nangak floodplain during 'Bird Week' tours on 22 June and 8 September 2009, on 30 June 2010 and on 2 September 2018. On each occasion, one or two birds were in paperbark woodland similar to that on the Mumeka-Kolorbidahbidah Road

Of the eight census sites where Shrike-tits were observed, six (five paperbark woodland sites and one 'mixed' woodland site) were located west of the Kolorbidahbidah turnoff. Birds were recorded in five of these sites on one morning in March 2009, and over two consecutive days in October 2008, indicating there were at least five permanent territories along this 10 km section of road. However, birds were never recorded at two sites near the middle of this section, leaving a gap of 2–5 km. Based on a total road length of 8 km, and assuming that each of the five pair-territories was roughly circular, the diameter of each territory would be 1.6 km and the average size of territories would be 201 ha. Calculating density based on a total road length of 8 km gives an estimated mean density of 0.01 birds ha^{-1}.

Apart from these sites west of the Kolorbidahbidah turnoff, Shrike-tits were found at two census sites located 1.2 km (PT) and 3.4 km (CA) respectively, north of the turnoff (Figure 2, Table 1), so likely involving one or two additional pairs. In addition to those recorded during the censuses, one pair was repeatedly recorded during 'Bird Week' tours in the Nangak area at the northern end of the Tomkinson floodplain, approx. 17 km from the nearest census site (CA). Therefore, the minimum population of the area surveyed was eight pairs. Using the polygon function in Google Earth, I estimate the area of suitable habitat on the eastern side of the Tomkinson River and south to my census sites west of the Kolarbidahbidah turnoff to be at least 100 km^2. Using this area and the above estimate of density suggests a population of approx. 50 pairs. This might even be conservative as there is probably suitable habitat to the south of the road, since low elevations (less than or equal to 10 m asl) extend at least 4 km inland.

Foraging behaviour

Shrike-tits were observed foraging at least once at each of the nine sites, involving months in both the Wet season (December, January and March) and the Dry season (June, August, October). All but two of the sites were in paperbark woodland, overwhelmingly dominated by Broad-leaved Paperbark, so it is not surprising that 89% of trees in which birds were seen to forage belonged to this species (Table 2). Other species utilised were eucalypts of three species, plus Coastal Paperbark and Cooktown Ironwood (Table 2). Birds of both sexes were observed to glean insects off leaves in Broad-leaved Paperbark (n=11) and *Corymbia* species (n=2). Other foraging manoeuvres seen were chiselling dead branches (n=5) at least once to extract a beetle, prying loose bark on branches (n=5), and piercing swollen twigs, probably to obtain the gall-forming insect larva (n=2). Other prey items were a spider and an unidentified arthropod extracted from tied leaves in two separate paperbarks. On one occasion, the stick case of a moth (Lepidoptera: Psychidae) was opened, its silk lining discarded, and its contents extracted before being carried to another tree.

Table 2. Trees in which Northern Shrike-tits were seen foraging in the study area. Values are numbers of records. GK, Nangak; other abbreviations as per Table 1.

Site	n (days)	Mv	Eucalypts	Ma/Rc
AC	5	34	2(Cl), 2(Et)	2(Rc)
FI	2	8		
SO	2	10		2(Ma)
CA	1	6		
GR	1	5		
NE	1	3		
QU	1	3		
PT	1		1(Cp)	
GK	1	4		
Total		73	5	4

Breeding

Although nesting was not observed directly, I watched birds building nests at one census site in two seasons, and saw juvenile birds, one of which was dependent, at two other sites. On 20 October 2008, from 07:15 hr I observed an adult female taking bark three times to a nearly complete nest approx. 15 cm below the top of a short (approx. 6.5 m high), spindly Broad-leaved Paperbark at Site NE. Almost one year later, at the same site, on 8 September 2009 from 07:30 hr, I observed the female taking bark, then spider-web, to an incomplete nest approx. 30 cm below the top of a short (approx. 7.5 m) Long-fruited Bloodwood (*Corymbia polycarpa*), while a nearby male, presumably its mate, called every 3–5 minutes for at least one hour.

On 3 March 2010, I watched an adult female feed a juvenile at least five times within 30 min at Site AC (Figure 2). Two days later, I observed an adult pair accompanied by a juvenile at Site CA (Figure 2), although no feedings were seen during the 15 min they were watched. As these two sites were separated by 6 km, it is extremely unlikely that these juveniles refer to the same individual.

Vocalisations

Shrike-tits were heard calling in each census month except for May. Calls were most frequently noted in October when call phrases were repeated up to 26 times without pause, and up to 10 times in March, but rarely in June, August, December and January. Call phrases in the study area typically consisted of three or four notes, the middle or the penultimate note being disyllabic with the second syllable upslurred, or two notes with the first strongly upslurred and the second slightly higher pitched than the start of the first note. On eight occasions, such phrases were uttered 4–10 (mostly 4–6) times in succession, with 1–3 sec between each phrase, but 15–26 times on three other occasions. Such series were repeated for up to 15 min, with gaps of approx. 30 sec to 5 min. Both sexes vocalised, though females were normally silent when the male was nearby. A descending chatter or chuckling call was also uttered by both sexes occasionally.

Discussion

Coastal location and habitat

There are only a few records of the Northern Shrike-tit in coastal or near-coastal localities. Barnard (1914) found the species at Borroloola, approx. 50 km upstream from the Gulf of Carpentaria on the McArthur River. William McLennan spent almost four months from September 1915 to January 1916 exploring the country around his camp near the mouth of the King River, approx. 80 km WNW of present-day Maningrida, but did not encounter the species (White 1917a, 1917b). In the northwestern Kimberley region, however, Hill (1911) collected a pair near the old Pago mission, approx. 20 km NNE of Kalumburu, within 700 m of the eastern shore of Napier Broome Bay, and saw another pair 17 km inland, in March and June 1910, respectively. Almost 90 years later, two birds were recorded in tall eucalypts along a creek at the ruins of Pago itself in May 1999 (Vigilante 1999). The 1990 record of two birds south of Ramingining (Robinson *et al.* 1992) was 48 km from the nearest coastline and 60 km from the nearest of the Tomkinson floodplain sites. Although the sites west of the Kolarbidahbidah turnoff were 33–36 km from the nearest coastline, birds seen in the northern section (Nangak) of the Tomkinson floodplain were only 18 km inland. Since the discovery of this population, however, a team of Northern Territory Government scientists and Yirrkala Rangers found the species on 21 June 2009 at a site approx. 75 km southwest of Nhulunbuy (ALA 2020: catalogue no. 1151673), only approx. 16 km from the southern shores of Arnhem Bay, northeast Arnhem Land.

On the McArthur River, Barnard (1914: 47) found only a few pairs, and they were "always on the dry stringybark ridges". Of 14 habitat records collated by Robinson & Woinarski (1992), seven (50%) were in woodlands dominated by Darwin Woollybutt, Darwin Stringybark and Shiny-leaved Bloodwood, while four others were in woodlands dominated by other species of eucalypts, such as Round-leaved Bloodwood, Hills Salmon Gum and Cabbage Gum (*C. polysciada*). Of the remaining three sites, one was dominated by Weeping Paperbark (*M. leucadendra*) and River Red Gum (*E. camaldulensis*), and another by a *Melaleuca 'miniata'* (presumably misnamed). In the Maranboy area, nests were found in open woodland dominated by Round-leaved Bloodwood, Darwin Box (*E. tectifica*), Large-leaved Cabbage Gum (*C. grandifolia*) and Cooktown Ironwood (Ward *et al.* 2009). In the Kimberley region, their habitat was described as open eucalypt forests and woodlands especially of Darwin Stringybark and Rusty Bloodwood (*C. ferruginea*) on sandstone hills (Johnstone & Storr 2004).

In contrast to the above findings, the Northern Shrike-tits in the present study occurred mainly in paperbark woodland on a seasonally-inundated floodplain, and were absent from the adjacent eucalypt forest, which was dominated by the same eucalypt species as at half of the locations collated by Robinson & Woinarski (1992). The habitat preference of this population is thus clearly atypical for the species, yet the estimated size of the population (8–50 pairs) and its occupation of the area for at least 14 years (2000–2014) suggests that seasonally inundated paperbark woodland is an eminently suitable habitat. Although its congener, the Eastern Shrike-tit, is regarded as a eucalypt forest specialist over most of southeastern Australia (Higgins & Peter 2002), in northeastern New South Wales and southeastern Queensland it occurs just as frequently in subtropical rainforest (Nielsen 1991; Gosper 1992; R. Noske, unpubl. data). Moreover, geographical variation in habitats occurs even among such apparently highly specialised tropical bird species as the Mangrove Robin (*Peneoenanthe pulverulenta*) and the Chestnut Rail (*Eulabeornis castaneoventris*) (e.g. Woinarski *et al.* 1998; Noske *et al.* 2018).

Breeding and vocalisations

Nests of the Northern Shrike-tit have hitherto been found only in eucalypts (including *Corymbia* spp.) and generally at heights greater than 10 m (Ward *et al.* 2009). In the Maranboy area, about halfway between Katherine and Mataranka, Ward *et al.* (2009) found five active nests, three of which were built or being built in Darwin Box, and one each in Large-leaved Cabbage Gum and Round-leaved Bloodwood. All nests were situated in the topmost branches of these trees, 10–15 cm from the edge of the crown, which varied in height from 13.4–16.0 m. The first nest I found on the Tomkinson floodplain was therefore the lowest (6.5 m) reported to date and the first nest recorded in a non-eucalypt.

Consistent with the literature, the breeding (egg laying) season of Northern Shrike-tits on the Tomkinson floodplain apparently spanned the late Dry season and the early Wet season. Nest construction began as early as the first week of September, whereas in the Maranboy area, it was first observed in October (Ward *et al.* 2009). However Shrike-tits sometimes abandon early nests before completion (Marchant 1985; Ward *et al.* 2009). While second broods are common in the Eastern Shrike-tit (Beruldsen 1965; Higgins & Peter 2002), it is not known whether Northern Shrike-tits are multi-brooded. Ward *et al.* (2009) concluded that the nesting season of Northern Shrike-tits is concentrated in the Build-up (October to December), and that late Wet season breeding is unlikely. Assuming that the duration of the nest cycle, from nest building to fledging of the young, is the same for the two species (approx. 47 days) (Marchant 1985; Higgins & Peter 2002), then birds building as late as November, such as two pairs in the Maranboy study, would be expected, if successful, to have fledglings from mid-December to early January. Although juveniles were seen in two territories on the Tomkinson floodplain in early March, juvenile Shrike-tits are known to be at least partially dependent on their parents for three months or longer (Noske 2003a).

There are few descriptions or publicly available recordings of vocalisations of the Northern Shrike-tit. At Leach Lagoon, approx. 40 km southeast of Katherine, the calls were described as commencing with the "familiar mournful descending notes of the Eastern species but … followed immediately with an upward group of similar duration and with a similar range of notes but in reverse" (Rix 1970: 173). Northern Shrike-tits on the Tomkinson floodplain never uttered descending notes. A sound recording of Northern Shrike-tits made by Chapman (2020; #057-090) at Drysdale River in the Kimberley region contains eight song phrases, each comprising four notes, the third quickly following the short second note, and the fourth sustained and strongly upslurred. Another recording made by Boersma (2015) at Beswick Creek, east of Maranboy, is similar consisting of a dozen or more song phrases, each comprising three quickly delivered short monotonal notes, mostly followed by a slightly higher-pitched, prolonged and upslurred fourth note, mostly after a slight pause. Calls on the Tomkinson floodplain also consisted of four notes and included upslurred notes, but evidently not at the end of the phrase. Such geographical variation is to be expected, especially since the latter population is isolated and a considerable distance from the Maranboy and Kimberley populations.

Foraging ecology and population density

Shrike-tits are arguably best known for their habit of ripping open and chiseling bark from living and dead trees with their massive bills to expose and obtain arthropod prey. Little is known about the foraging ecology of the Northern Shrike-tits but near Borroloola, Barnard (1914) observed them hunting insects among "dead leaves and dry tree stems", while at Larrimah, Sedgwick (1947) saw two birds tearing bark from a limb in a manner similar to that employed by Eastern Shrike-tits. At the Ramingining site, two birds were observed prising bark flakes from branches of Darwin Woollybutt and Shiny-leaved Bloodwood, as well as the bark of one standing dead tree (Robinson & Woinarski 1992). Darwin Woollybutt and Shiny-leaved Bloodwood have smooth bark on the branches and upper trunk, but shed bark is not retained on the tree.

In attempting to explain the scarcity of Northern Shrike-tits, Robinson & Woinarski (1992) drew attention to the paucity of eucalypts with decorticating bark in tropical Australia and the absence or poor representation of subgenera *Monocalyptus* and *Symphomyrtus*, which are widespread in southeastern and southwestern Australia (Brooker & Kleinig 1994). They argued that such differences in eucalypt bark characteristics and species composition, as well as the greater rainfall seasonality and higher fire frequency of the monsoon tropics, might reduce the abundance of bark-dwelling arthropods, and hence, bark-foraging birds such as the Northern Shrike-tit. Accordingly, Robinson & Woinarski (1992) proposed that Northern Shrike-tits might have to forage over huge areas of woodland to find sufficient food.

However, my observations reveal that some populations of Northern Shrike-tits, such as those on the Tomkinson floodplain, forage as much on foliage as on bark. Indeed, the importance of this foraging technique varies geographically and intersexually among Shrike-tits. Although Eastern Shrike-tits in the Southern Tablelands of New South Wales took almost all of their prey from loose and decorticating bark (Recher *et al.* 1985), in the Northern Tablelands females foraged mostly on leaves, petioles and thin ribbons of bark (Noske 2003b). In southwestern Western Australia, Recher (2006) found that Western Shrike-tits (*Falcunculus leucogaster*) obtained most of their prey by gleaning foliage, and argued that they were forced to do so because the bark on local eucalypts does not decorticate in long ribbons or accumulate on the tree as it does in the forests of southeastern Australia. As eucalypt foliage appears to support smaller and thus less rewarding prey than hanging ribbons of bark, pairs may be forced to forage over very large areas to obtain adequate food (Recher 2006).

As well as being sparsely distributed, the Northern Shrike-tit appears to occur at lower densities than its eastern counterpart, though not as low as that of the Western Shrike-tit. The population density of Eastern Shrike-tits in eucalypt forests in New South Wales varied from 0.01–0.15 birds ha^{-1} on the Northern Tablelands (Howe & Noske 1980; Ford *et al.* 1985) to 0.05–0.56 birds ha^{-1} on the Southern Tablelands (Recher *et al.* 1985). In preferred eucalypt woodland in the Maranboy area, the population density of Northern Shrike-tits was approximately 1.25 adults km^{-2} (Woinarski & Ward 2012), equivalent to 0.013 adults ha^{-1}, which is only slightly higher than that estimated here for the Tomkinson floodplain population (0.01 adults ha^{-1}). That population densities in two such different habitats were similar suggests that the abundance of suitable prey on paperbark trees on the Tomkinson floodplain does not differ markedly from that on eucalypts in the Maranboy area.

The Northern Shrike-tit is one of several bird species for which there were, until recently, few or no records from Arnhem Land, but they have recently been found in the seasonally inundated paperbark woodland of the Tomkinson floodplain (see Noske 2020, this issue). Some of these species, including the Northern Shrike-tit, appear to avoid the eucalypt forest that not only adjoins the floodplain, but dominates the landscape to the east and west. Moreover, while the abundance of foliage-gleaning insectivorous birds in the paperbark woodland was similar to that of adjacent eucalypt forests, their species composition differed markedy (Noske & Franklin in prep.). This suggests that the floodplain environment and/or paperbark trees are favourable for food and/or shelter from predators for some species, but not others. Future research could compare the abundance, diversity and biomass of arthropods on the bark and foliage of paperbarks and eucalypts to determine how these substrates and tree species differ in their value to birds as sources of prey

To the south of the road west of the Kolarbidahbidah turnoff, the land rises gradually for 20 km to the sandstone uplands with its distinctive flora and fauna. Given that the only other known location for Northern Shrike-tits in the western half of Arnhem Land is 60 km to the southeast of the nearest Upper Tomkinson floodplain sites, the Tomkinson River population appears to be rather isolated. Moreover, as the pair at the other site was observed foraging only on the bark of each of the three common eucalypt species (Robinson *et al.* 1992), their foraging behaviour might also differ from that of the Tomkinson River population. As the unique plier-like bills of shrike-tits have almost certainly evolved as an adaptation for tearing bark and chiselling dead wood, variation in bill dimensions might be a useful indicator of niche specialisation in different species and populations. As well as being larger, male Eastern Shrike-tits have proportionally larger bills than females (Noske 2003). Unfortunately there are very few specimens and capture records for the Northern Shrike-tit and consequently insufficient mensural data to validly compare both sexes of each species, so future research might use photographs of different populations to explore the relationship between morphology and foraging ecology in these intriguing birds.

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New localities for nine bird species in Arnhem Land, including those for the notable Gouldian Finch, Red Goshawk and Hooded Robin

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Abstract

Due to its remoteness and restricted access, Arnhem Land remains one of the least ornithologically explored regions of Australia. This paper documents records of nine bird species which result from bird tours and surveys in the area surrounding Arnhem Land Barramundi Lodge, south of Maningrida, western Arnhem Land, from 2008 to 2018, and assesses their significance based on the historical literature, two national bird atlases and online database records. Three species, Red Goshawk (*Erythrotriorchis radiatus* Accipitridae), Rufous Owl (*Ninox rufa* Strigilidae) and Gouldian Finch (*Chloebia gouldiae* Estrildidae), are historically known from localities to the west (Gunbalanya and King River) and east (Gove Peninsula), so their presence in the study area might be expected. Observations of two nesting pairs of Red Goshawks represent the first breeding records of this rare species for Arnhem Land. Annual sightings of predominantly juvenile Gouldian Finches and a record of recently-fledged birds suggest local breeding. Four other species, Hooded Parrot (*Psephotellus dissimilis* Psittaculidae), Yellow-tinted Honeyeater (*Ptilotula flavescens* Meliphagidae), Black-chinned Honeyeater (*Melithreptus gularis laetior* Meliphagidae) and Hooded Robin (*Melanodryas cucullata* Petroicidae), are largely known in the Top End from the semi-arid Katherine-Mataranka region, and the near-coastal observations documented here represent considerable extensions of the geographical ranges of all but the Hooded Parrot. All four species were associated with the seasonally-inundated paperbark woodland of the Tomkinson floodplain, though only the Yellow-tinted Honeyeater was abundant. The small population of Hooded Robins appears to be highly isolated and thus vulnerable to local, if not regional, extinction. Finally, I summarise records of the Mangrove Grey Fantail (*Rhipidura phasiana* Rhipiduridae) and the migratory Grey Fantail (*Rhipidura albiscapa* Rhipiduridae) in Arnhem Land, which help to define their ranges in the Top End of the Northern Territory.

Introduction

Occupying almost half of the Top End of the Northern Territory, Arnhem Land is one of the few non-desert regions of Australia that is owned and managed by indigenous people. Due to its remoteness and restricted access, however, it remains one of the least ornithologically explored regions of Australia. While chronicling of the avifauna of the adjacent Cobourg Peninsula began as early as 1840 with the arrival of John Gilbert at the settlement of Victoria in Port Essington (Fisher & Calaby 2009), it was another 75 years before ornithological exploration began in Arnhem Land (Noske 2017). In June 1915, William Rae McLennan set sail from Thursday Island to collect specimens and eggs of birds in Arnhem Land and the Gulf of Carpentaria for H.L. White, the eminent grazier-ornithologist. After six days travelling up and down the Liverpool River in search of a source of fresh water, he arrived on 26 September at the mouth of the King River, approx. 150 km southeast of Victoria settlement. McLennan spent the next four months in the King River area, recording 156 bird species before being forced to abandon the camp and return to Roper River after Aborigines raided his cutter and stole most of the provisions. McLennan's King River camp is significant in being roughly halfway between Gunbulanya (70 km to the southwest) and Maningrida (80 km to the east).

Since that time, most ornithological attention has focussed on northeast Arnhem Land. During WW II, Cyril Humphries observed the birds around Melville Bay while stationed with the Royal Australian Air Force at Gove (now known as Nhulunbuy) Airfield over 15 months from July 1944 to October 1945 (Humphries 1947). Only three years later, the American ornithologist Herbert Deignan spent eight weeks during July and August 1948 collecting birds at Yirrkala for the American-Australian Scientific Expedition to Arnhem Land (Deignan 1964). Three decades later, Boekel (1976) recorded the birds he observed within 30 km of Nhulunbuy, where he was stationed as a school teacher for 10 months in 1974. During the 1990s, the Conservation Commission of the Northern Territory conducted systematic faunal surveys of Nanydjaka (Cape Arnhem) on Gove Peninsula (Gambold *et al.* 1995) and the Wessel and English Company Islands, off the coast of northeast Arnhem Land (Woinarski *et al.* 2001), as well as undertaking aerial surveys of waterbirds around the whole coast of the Top End, including Arnhem Land (Chatto 2000, 2006). The birds of the rehabilitation areas at the Gove bauxite mine were also investigated from 1998 to 2000 (Brady 2005; Brady & Noske 2010).

Northwest Arnhem Land has received less ornithological attention than the northeast. After his stay in Yirrkala, Deignan (1964) collected birds in Oenpelli (now Gunbulanya), close to Arnhem Land's western boundary, from 21 September to 6 November 1948. Two decades later, members of the fifth and final Harold Hall Expedition also collected birds from a site 16 km southwest of Oenpelli Mission for three weeks in September 1968 (Hall 1974). In the same year, scientists from the Division of Wildlife Research, CSIRO, completed their bird surveys of Cobourg Peninsula, permitting a comparison with Gilbert's seminal field studies (Frith & Hitchcock 1974; Noske 2017).

As part of a study of the Top End-endemic White-throated Grasswren (*Amytornis woodwardi*) (Noske 1992), Holmes & Noske (1990) used a helicopter to access four remote locations on the sandstone massif of western Arnhem Land in December 1987 and January 1988, obtaining the first records of this and other sandstone-endemic species in the interior of Arnhem Land. Soon afterwards, Robinson *et al.* (1992) reported range extensions of 20 bird species from the Gulf of Carpentaria and Arnhem Land. Both Holmes & Noske (1990) and Robinson *et al.* (1992) stressed the dearth of basic distributional and habitat information for many bird species in the region and the need for greater survey effort.

In June 2008, the author was contacted by Alex Julius, owner of Arnhem Land Barramundi Nature Lodge (ABNL), to assess the feasibility of bird tours in the area, and one month later, the first of many ABNL-hosted 'Bird Weeks' was conducted with co-guides Johnny Estbergs and Dick Eussen. During this and subsequent tours, we observed several species that were outside their known range according to the published literature. This paper documents these observations, except for those of the Northern Shrike-tit which are presented separately in this issue of *Northern Territory Naturalist.*

Study area and methods

Arnhem Land is bounded to the north by the Arafura Sea and to the east by the Gulf of Carpentaria. On the west, it is bordered largely by Kakadu National Park (133°00'E), while its irregular southern boundary is marked by the 14°00'S parallel approximately as far as the meridian 134°15'E, and the Roper River in the southeast around 14°42'S (Figure 1a). In this report I use the terms northern and southern Arnhem Land to refer to those parts north of 13°S and south of 14°S, respectively, and central Arnhem Land for those parts between 13°S and 14°S.

This report is based on records collected mainly from 2008 to 2010 in the area within 20 km of ABNL, including the township of Maningrida, which is situated on the mouth of the Liverpool River, Western Arnhem Land (Figure 1b). Established in 2004 by Alex Julius as a fishing lodge, ABNL is located 17 km SSE of Maningrida on a plateau which overlooks the vast floodplain of the Tomkinson River, a tributary of the Liverpool River. Following a reconnaissance trip by the author in June 2008, ABNL hosted the first Arnhem Land 'Bird Week' one month later, exploring the Liverpool and Tomkinson Rivers, and Haul Round Island by boat, and many woodland sites within two hours drive from ABNL. Since then, one or two tours of five to seven days, mostly in July and August, were undertaken annually until 2015 (Table 1), when ABNL was purchased by Outback Spirit Tours Pty Ltd. Subsequently, 'Bird Week' tours were undertaken in September, though only two or three days were devoted to the ABNL environs, while a similar period was spent at the recently-opened Murwangi Safari Camp (Figure 1a) on the western edge of the Arafura Swamp (Noske & Johnstone 2018; Noske *et al.* 2018). All the ABNL bird tours included a vehicular trip to: (1) Nangak floodplain lying between the Tomkinson River and the rocky escarpment on which ABNL and Djinkarr Ranger

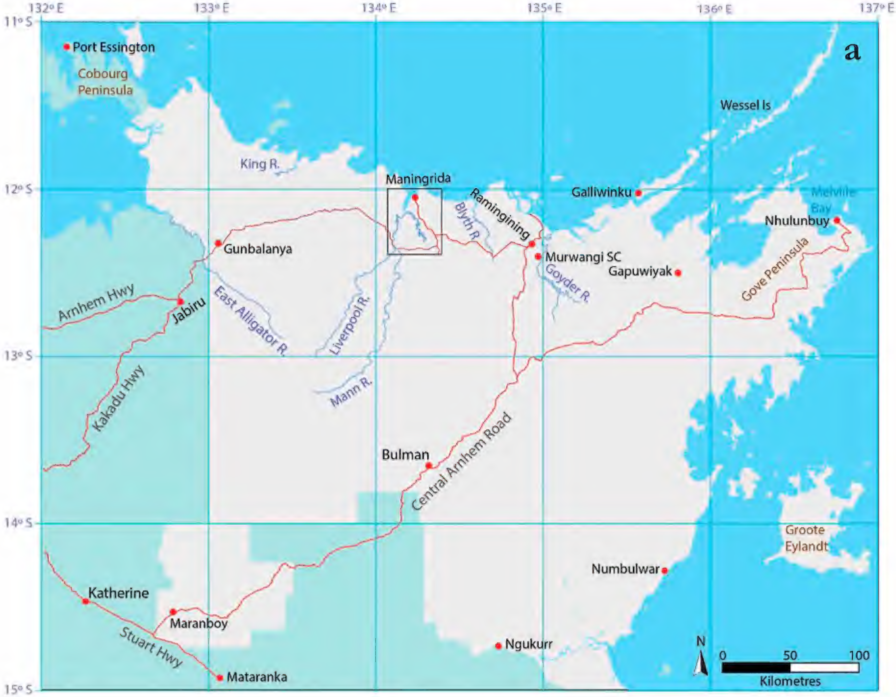
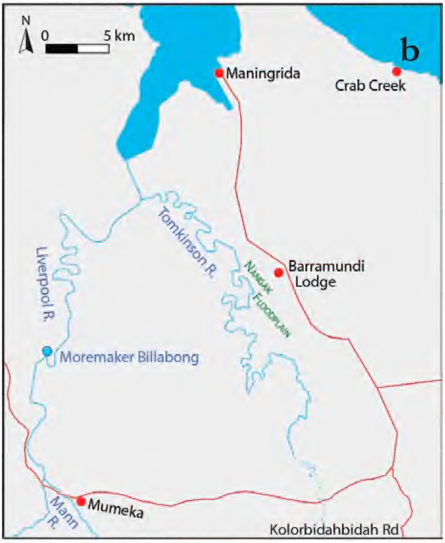


Figure 1a. Map of Arnhem Land, showing localities mentioned in the text. (Niven McCrie).
Figure 1b. Showing enlargement of the study region. (Niven McCrie)



Station (1.7 km south of ABNL) were perched, and (2) several waterholes along a 10 km section of the main road from Maningrida to Gunbalanya, 15–25 km east of the Mann River crossing or 0.5–10.5 km west of the turnoff to Kolorbidahbidah, which is 18 km SSE of ABNL. Hereafter I refer to the latter section of the road as the Upper Tomkinson floodplain.

In addition to co-leading bird tours, I conducted 20 min censuses of up to 20 x 2 ha sites within 20 km of ABNL in each of six months (October 2008, January, May, August and December 2009, and March 2010) for a study comparing the avifauna of two distinct local habitats: (1) eucalypt forest dominated by Darwin Woollybutt

(*Eucalyptus miniata*) and/or Darwin Stringybark (*Eucalyptus tetradonta*) on the rocky plateau (60–80 m asl), and (2) paperbark woodland on the seasonally-inundated Upper Tomkinson floodplain (4–20 m asl). Sites were sampled three times over two to three consecutive days except in January, when four of the paperbark plots could not be accessed due to flooding, and December, when eucalypt sites were not sampled due to inclement weather, and paperbark sites were sampled only once. The detailed results of that study will be presented elsewhere.

In the results below, I have summarised the records of the selected species from both 'Bird Week' tours and bird surveys, as well as historical records, including those from *The Atlas of Australian Birds* (Blakers *et al.* 1984; hereafter *Atlas 1*) and *The New Atlas of Australian Birds* (Barrett *et al.* 2003; hereafter *Atlas 2*). *Atlas 1* covered the period from 1977–1981, while *Atlas 2* covered 1998–2002. The one-degree cell encompassing Maningrida (12°00'–12°59'S, 134°00'–134°59'E, hereafter abbreviated as 12/134) also includes the township of Ramingining. It is bordered to the west and east by one-degree cells encompassing Gunbalanya (12/133) and Galiwinku (12/135), respectively, and to the south by the cell encompassing Bulman (13/134) on the Central Arnhem Road. Further east is the Gove Peninsula (12/136) encompassing Nhulunbuy and Yirrkala. The geographical co-ordinates of many records are provided in Appendix 1.

For additional records from Arnhem Land, I downloaded and scrutinised online data from eBird (2020) and the *Atlas of Living Australia* (ALA 2020) for each species, and where geographical co-ordinates were not given for a particular location, I used *Google Earth* to determine approximate coordinates. Where considered relevant, I have cited the name of the observer and the eBird checklist number (beginning with 'S'); for example "eBird 2020: M. Barton, S15734020") or *Atlas of Living Australia* catalogue number (preceded by 'ALA#') of the record. Unless otherwise stated, distances between places were measured as straight lines using *Google Earth*. The question of whether records constitute extensions or the filling of gaps in the range for a particular species, is dependent on sources and publication dates of information. In this paper I have based my assessments on maps and information published in the *Handbook of Australian, New Zealand and Antarctic Birds* (Higgins 1999), in combination with *Atlas 2*, since maps in field guides (Menkhorst *et al.* 2017) are too generalised and small in scale to be accurate.

Results

RED GOSHAWK (*Erythrotriorchis radiatus*)

Considered Vulnerable both nationally and within the Northern Territory, the Red Goshawk is widely, but patchily distributed across the Top End (Marchant & Higgins 1994), with a major stronghold on the Tiwi Islands (NTG 2020). It was first recorded in Arnhem Land by McLennan who collected one specimen near his King River camp in November 1915 (White 1917b). While distribution maps suggest that it is absent from eastern Arnhem Land (Marchant & Higgins 1993; Barrett *et al.* 2003), Humphries (1947)

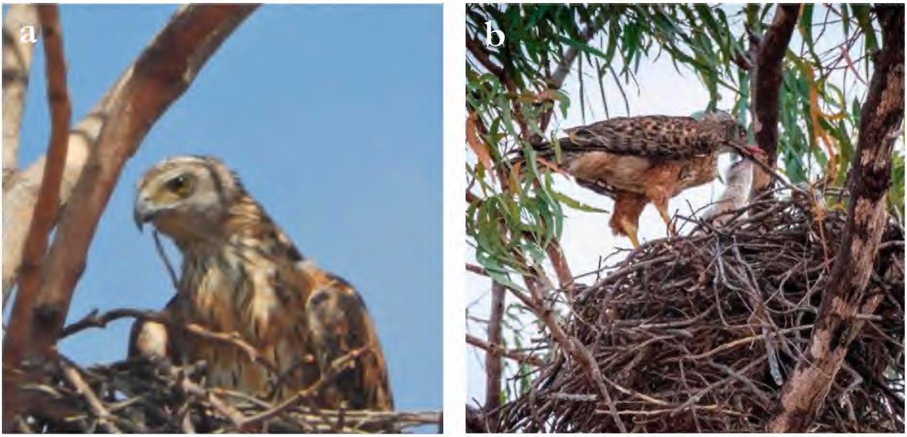


Figure 2. Red Goshawk (*Erythrotriorchis radiatus*), on nest near Arnhem Land Barramundi Nature Lodge. **a.** adult probably incubating, 28 September 2017 (Graham Hall); **b.** adult feeding nestling, 4 October 2016. (Leigh Hall)

recorded the species occasionally in the Melville Bay (Gove Peninsula) region in the mid-1940s, and Deignan (1964) observed a bird between Yirrkala and Melville Bay in August 1948. During *Atlas 1* (1977–1981) it was recorded from the Gunbalanya and Nhulunbuy cells, but not the Maningrida cell, and there were no records from Arnhem Land at all during *Atlas 2* (1990–2002).

The Red Goshawk was first recorded in the study area on 19 July 2008 when an adult was seen diving at Pacific Black Ducks (*Anas superciliosa*) while it was being chased by Little Corellas (*Cacatua sanguinea*) at the Crater Lake (4 km SE of ABNL). On the following day, J. Estbergs spotted a nest at approx. 18 m in a tall (20 m) Darwin Stringybark, approx. 1.5 km from ABNL. In the following year, an adult was observed sitting on this nest on 27 and 28 August 2009, and on each day from 5–9 September. There was no evidence of activity at this nest during tours in 2010 and 2011, though on 18 July 2010, a bird was recorded at or near Maningrida (eBird 2020: M. Barton, S15734020). In July 2012, an adult was seen sitting at a new nest in a tree approx. 50 m away, and this nest was used in each of the following five years (Figure 2a; J. Estbergs pers. comm.). In 2016, the nest contained a single large chick with an adult in attendance on 26 September, and later the chick was observed being fed with a small bird. An adult was again sitting on the nest from 22 to 24 September 2017, but there was no activity during September 2018. J. Estbergs found another nest on the road to Crab Creek, approx. 15 km east of Maningrida, which was attended by a female on 7 September 2009, and again on 10 December 2010. Similar to the first nest, it was built in a tall Darwin Stringybark (approx. 22 m high), at approx. 18 m from the ground.

Table 1. Maximum number of birds (and frequency of sightings, in brackets) of notable species recorded during bird tours based at Arnhem Land Barramundi Nature Lodge from 2008–2018. The abbreviation "nr" signifies not recorded. The data from August 2010 to 2015 were provided by J. Estbergs.

Year	Start date	Finish date	Red Goshawk	Hooded Parrot	Rufous Owl	Black-chinned Honeyeater	Gouldian Finch
2008	19 July	26 July	1 (1)	4 (2)	nr	4 (3)	185 (2)
2009	22 June	28 June	1 (4)	16 (1)	nr	1+ (2)	25 (3)
2009	6 September	11 September	2 (2)	nr	2 (1)	3 (1)	60 (3)
2010	27 June	4 July	nr	36 (3)	1 (1)	1+ (1)	10 (2)
2010	27 August	1 September	nr	? (1)	1 (1)	1 (1)	? (2)
2011	1 July	8 July	nr	nr	nr	2 (1)	2 (1)
2011	16 July	21 July	nr	2 (1)	nr	1+ (1)	nr
2012	5 July	11 July	1 (1)	6 (1)	1 (1)	1+ (2)	1+ (3)
2012	30 September	4 October	1 (2)	7 (3)	nr	1+ (2)	3 (2)
2013	21 August	27 August	nr	3 (1)	nr	nr	8-10 (3)
2015	17 August	22 August	1 (4)	nr	nr	1+ (1)	nr
2016	26 September	5 October	2 (6)	nr	2 (1)	nr	25 (2)
2017	22 September	24 September	1 (3)	nr	nr	nr	nr
2018	2 September	4 September	nr	nr	nr	nr	nr

RUFOUS OWL (*Ninox rufa*)

Widely distributed across the Top End (Higgins 1999), the Rufous Owl was apparently first recorded in Arnhem Land by McLennan who collected three of six birds that he found in mangroves and two small patches of monsoon rainforest along the King River from 15–22 October 1915 (White 1917a). Distribution maps suggest that the Rufous Owl occurs across most of Arnhem Land (Higgins 1999). In northeastern Arnhem Land, Humphries (1947) sighted one pair in dense rainforest near Melville Bay, though neither Boekel (1976) nor Officer (1976) recorded it around Nhulunbuy. During *Atlas 1*, it was recorded from Gunbalanya and Nhulunbuy cells (Blakers *et al.* 1984). In July 1990, Robinson *et al.* (1992) observed one bird in a vine thicket with tall canopy cover, 50 km south of Ramingining (49 km SW of the nearest coast) and another in evergreen forest along Annie Creek (76 km south of Ramingining). In the following month, a bird was sighted approx. 5 km southwest of Ramingining (J.C.Z. Woinarski, ALA #1128979). During *Atlas 2*, one bird was found 5 km northeast of Annie Creek on 27 July 1999 (K. Brennan, ALA #1081086) and another at Port Bradshaw, 38 km south of Nhulunbuy, on 9 July 2000 (ALA #2071221), in the Maningrida and Nhulunbuy cells, respectively.

On 8 September 2009, during 'Bird Week', J. Estbergs discovered two birds in a small patch of monsoon rainforest near the Cadell River, 35 km ESE of Maningrida. The site was visited again on 1 July and 30 August 2010, when one bird was seen. In addition, two birds were sighted in tall mangroves during a boat cruise on the Tomkinson River on 4 October 2016 (C. Brady pers. comm.). The most recent record is from Nhulunbuy, where one bird was observed in March 2017 (eBird 2020; C. Wiley/K. Rose, S35080317).

HOODED PARROT (*Psephotellus dissimilis*)

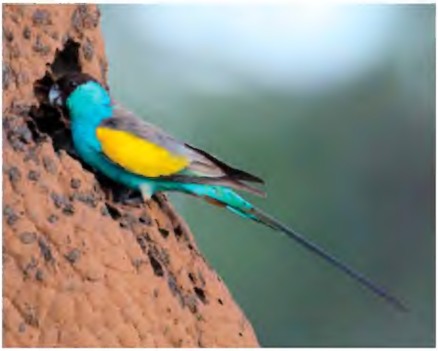


Figure 3. Hooded Parrot (*Psephotellus dissimilis*), adult male at nest, near Katherine. (Marc Gardner)

Endemic to the Top End, the Hooded Parrot (Figure 3) is mainly known from inland localities, particularly in the Pine Creek and Katherine-Mataranka regions (Higgins 1999). The species has not been recorded on Cobourg Peninsula or Gove Peninsula, but in the 1940s it was recorded at Banyan Island at the mouth of Woolen River, approx. 30 km east of Ramingining (Barrett 1949 in Higgins 1999). While there are no historical records from Gunbalanya, it was allegedly observed at a site 84 km ESE of Gunbalanya (or 47 km west of Maningrida), in the Gunbalanya cell, during *Atlas 1* (Blakers *et al.* 1984; ALA # 534047). During the same period (1977–1981), Reed & Tidemann (1994) found five nests at 'Mann River' and 'Arafura Homestead' (now Murwangi Safari Camp), both sites in the Maningrida cell and 25–30 km inland from the nearest coast. Further inland, Robinson *et al.* (1992) recorded five birds in one flock and occasional other pairs 50 km south of Ramingining on 3 August 1990. On 25 August 1996, the species was allegedly seen at a site approx. 7 km SE of Kolorbidahbidah or 116 km north of Bulman (ALA #62183223), but the location is very remote. There were no records from Arnhem Land during *Atlas 2* (1998–2002).

Hooded Parrots were first observed near ABNL on 26 July 2008, when two birds were observed on the Nangak floodplain, approx. 16 km from the mouth of the Liverpool River, and another two at a soak on the Upper Tomkinson floodplain (Table 1). On 9 May 2009, a pair was found foraging beside the road approx. 1 km from ABNL, and on 22 June, 16 were counted on the Nangak floodplain, although they were not re-sighted during the following six days. In 2010, 20 birds were seen near ABNL as early as 29 March (eBird 2020: Ian Davies, S19288988), while during 'Bird Week' (27 June–4 July) flocks of up to 36 birds were seen on three days on the Nangak floodplain. On the Nangak floodplain, the birds appeared to favour the area where the recently burnt floodplain abutted the unburnt low paperbark woodland with its tall grasses; four birds were observed chewing on the wall of a magnetic termite mound (J. Estbergs *in litt.).* Some were still present at Nangak in late August 2010 (Table 1). Small numbers were observed each year from 2011 to 2013, including early October 2012, but none were seen from 2015 to 2018.

More recently, on 13 June 2019, three birds were reported from a site 37 km by road west of the Gapuwiyak turnoff from the Central Arnhem Road (eBird 2020: M. Griffith, S57336145), which is 79 km ESE of the abovementioned site of Robinson *et al.* (1992)

and approx. 65 km SSE of Banyan Island. This appears to be the easternmost record of the species. The only record of the species from central Arnhem Land was made on 5 August 2007 at a site 38 km NE of Bulman on the Central Arnhem Road (eBird 2020: S. Sparkman, S70858645).

YELLOW-TINTED HONEYEATER (*Ptilotula flavescens*)

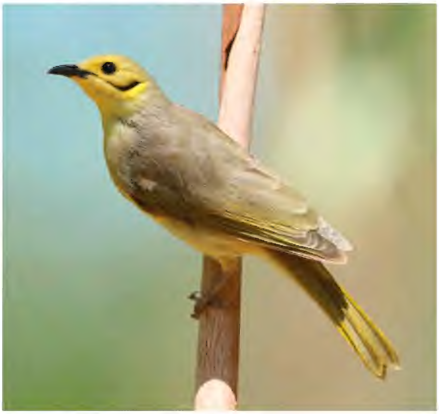


Figure 4. Yellow-tinted Honeyeater (*Ptilotula flavescens*), East Point Reserve, Darwin. (Marc Gardner)

In the Northern Territory, the Yellow-tinted Honeyeater (Figure 4) is known mainly from the Katherine-Mataranka and Victoria River-Timber Creek regions in the south-central and southwest of the Top End, respectively (Storr 1977; McCrie & Watson 2003). At Yinberrie Hills, approx. 50 km northwest of Katherine, it was one of the most abundant species, especially during the Wet season (Woinarski & Tidemann 1991). Higgins *et al.* (2001) presumed the species was largely absent from Arnhem Land, except for Gove Peninsula where it was recorded once only by both Humphries (1947) and Boekel (1976). There are no historical records from King River, Cobourg Peninsula, or Gunbalanya. Moreover, there were no records of the species from northern Arnhem Land during *Atlas 1*, but during *Atlas 2*, I recorded the species 20 km east of the Mann River crossing on the Upper Tomkinson floodplain on 27 September 2000.

During the study period, the Yellow-tinted Honeyeater was found to be a common resident of woodlands dominated by Broad-leaved Paperbark on the seasonally inundated floodplain of the Tomkinson River catchment. Each year from 2008 to 2018 it was recorded during 'Bird Week' tours at Nangak, and was especially abundant around the well-wooded billabongs where Cajaput (*Melaleuca cajaputi*) was co-dominant with *M. viridiflora*. During 262 censuses, I recorded this species 57 times (21.8%), but almost exclusively at paperbark woodland sites. Indeed, Yellow-tinted Honeyeaters were the fourth most frequently encountered and sixth most abundant species on the paperbark woodland sites (R. Noske unpub. data). Observations of recently-fledged birds on the Nangak floodplain and the Upper Tomkinson floodplain in March (n=1), June (n=3) and September (n=2) indicate that egg laying occurred from February to August (R. Noske unpub. data), whereas at Yinberrie Hills, breeding (unspecified) was noted from December to May (Woinarski & Tidemann 1991).

Further east, the species was found to be common around the Arafura Swamp, with up to 27 individuals at survey sites (n=10), 1–32 km from Murwangi Safari Camp from 10 September 1998 to 21 September 1999 (K. Brennan, *Fauna Atlas NT*; ALA#1077448, 1078593, 1078762, 1078797, 1079288, 1080116, 1080786, 1081181, 1081903, 1081937). Almost two decades later, it was frequently recorded in both paperbark and eucalypt woodlands around Murwangi Safari Camp during 'Bird Weeks' in September and October 2016, September 2017, and 31 August–1 September 2018 (R. Noske, unpub. data).

Outside the Maningrida-Arafura Swamp area, eBird (2020) records from northern Arnhem Land comprise one from Lake Evella beside Gapuwiyak on 18 August 2016 (J. and P. Manins, S41888048; 12°30'S, 135°48'E) and another from a site approx. 24 km to the south on the Bulman-Nhulunbuy Road in August 2005 (C. Curson, S16600573; 12°42'S, 135°45'E), both within the Galiwinku cell. About 60 km further east, two birds were observed in July 2012 at a site approx. 84 km SW of Nhulunbuy (C. Wiley, S11145533; 12°46'S, 136°17'E). In central Arnhem Land, the northernmost records are from the vicinity of Annie Creek (old Goyder River crossing), approx. 60 km south of Murwangi, in September 1999 (K. Brennan, ALA #1079703, 1080236) and October 2016 (eBird 2020: K. Rose, S31956465).

BLACK-CHINNED HONEYEATER (*Melithreptus gularis laetior*)

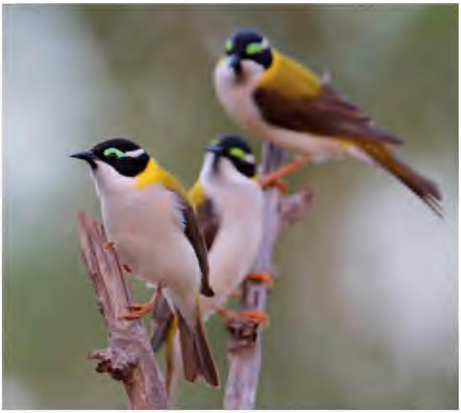


Figure 5. Black-chinned Honeyeater (*Melithreptus gularis laetior*), Ngukurr, southeast Arnhem Land. (Marc Gardner)

Like the Yellow-tinted Honeyeater, the 'golden-backed' subspecies of the Black-chinned Honeyeater (Figure 5) is known mainly from the Katherine-Mataranka and Victoria River-Timber Creek regions in the south of the Top End, though it is much less common than the former species (Storr 1977; McCrie & Watson 2003). At Yinberrie Hills, its mean density was lower than that of the Yellow-tinted Honeyeater (0.01 vs 0.55 birds ha^{-1}, respectively) (Woinarski & Tidemann 1991), and although more abundant in riparian sites than in non-riparian sites surveyed by Woinarski *et al.* (2000), it was found on the fewest sites, and had the lowest density of all honeyeaters except for the Yellow-throated Miner (*Manorina flavigula*). There are no historical records of the species in Arnhem Land, and Higgins *et al.* (2001) considered it to be absent from the region. The distribution map in Menkhorst *et al.* (2017) indicates that it is absent from northern and eastern Arnhem Land. Indeed, there were no records from northern or central Arnhem Land during *Atlas 1*, but during *Atlas 2*, it was recorded in the Bulman cell at a site 35 km northeast of Bulman (130 km SSW of Ramingining) on 29 September 2000 (*NT Fauna Atlas*; ALA #2057598), and another site 91 km south of Ramingining on 1 January 2001 (J.C.Z. Woinarski, ALA #1069523).

In the study area, Black-chinned Honeyeaters were first recorded on the outer edge of the Nangak floodplain, approx. 300 m from ABNL on 27 June 2008, and during the subsequent 'Bird Week' (July 2008) from two sites on the Upper Tomkinson floodplain, as well as in eucalypt woodland dominated by Salmon Gum (*Eucalyptus tintinnans*), approx. 8 km south of the turnoff to Kolorbidahdah. They were also recorded on 10 (3.8%) of my 262 censuses during 2008–2010, involving five sites, four of which were in paperbark woodland, and two in mixed woodland. At 18:00 hr on 21 January 2009, a group of five birds was observed huddling to roost on an exposed horizontal branch of a tree approx. 300 m below Djinkarr Ranger Station. On 21 June 2009, a nest with young was found approx. 1 km southwest of the Kolorbidahbidah turnoff, with at least four adults in attendance. The nest was approx. 7.5 m from the ground and approx. 1.5 m below the top of a Round-leaved Bloodwood (*Corymbia latifolia*). This appears to be the first breeding record north of 14°S in the Top End. The species was subsequently recorded at least once on each bird tour until 2013, after which it was recorded once in 2015 only (Table 1).

Although I did not encounter the species at Murwangi Safari Camp during bird tours in 2016–2018, it was reported from sites near Annie Creek (12°58'S, 135°01'E), 54–61 km south of Murwangi, on 27 April 2016 (eBird 2020; K. Rose, S29254974) and 2 October 2016 (S31956465).

HOODED ROBIN (*Melanodryas cucullata*)

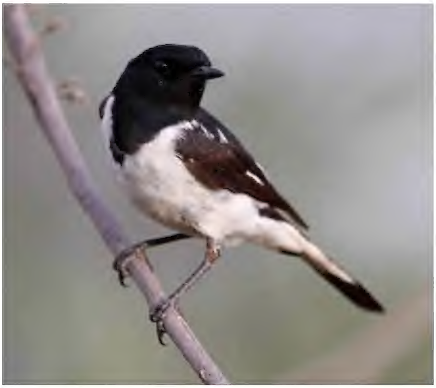


Figure 6. Hooded Robin (*Melanodryas cucullata*), male, near Katherine. (Marc Gardner)

In the Top End, the Hooded Robin (Figure 6) is mainly confined to inland areas, such as around Pine Creek and Timber Creek (Boekel 1980; Woinarski & Tidemann 1991; McCrie & Watson 2003), though there are scattered records from Kakadu National Park (Brooker & Parker 1985). The sole historical record from northern Arnhem Land is of a specimen (H.L. White Collection, Museum of Victoria) collected by W. McLennan from the Goyder River on 8 September 1915 (White 1917b). The *Atlas of Living Australia* gives the geographical co-ordinates of the specimen as approx. 1 km west of Arafura Homestead (i.e. present-day Murwangi Safari Camp), though McLennan's diary (White 1917a) indicates that the furthest he travelled by boat from the river's mouth was 42 km, where he described the eastern bank as the edge of "a vast mangrove swamp", which on *Google Earth* clearly approximates the northern end of the Arafura Swamp, approx. 11 km NNE of the homestead. An alleged specimen from Cobourg Peninsula (Frith & Hitchcock 1974) was probably collected from the Kimberley region (Fisher & Calaby 2009). There were no reports of the species from Arnhem Land during either *Atlas 1* or *Atlas 2*, although it was allegedly recorded from a site approx. 7 km south of Nhulunbuy on both 12 February and 1 June 1980 (ALA #370785 and #370786, respectively). Recent published distribution maps (Higgins & Peter 2002; Menkhorst *et al.* 2017) indicate that it is entirely absent from Arnhem Land.

During my 2009–2010 surveys, I recorded the species six times, involving five sites, all on the Upper Tomkinson floodplain. The four sites with single observations were in paperbark woodland dominated by Broad-leaved Paperbark (6–9 m high) on the seasonally inundated floodplain, whereas two sightings were made at the fifth site which was in open woodland situated on a stony rise, dominated by somewhat stunted or sparsely-foliaged eucalypts (approx. 10 m high), including Darwin Stringybark and Round-leaved Bloodwood with groves of Quinine Tree (*Petalostigma pubescens*). Records covered all but one (March) of the five sampled months. There are no eBird records for the species in Arnhem Land.

GREY FANTAIL (*Rhipidura albiscapa*) and MANGROVE GREY FANTAIL (*R. phasiana)*

Prior to Ford's (1981) review, the Mangrove Grey Fantail was treated as a subspecies of the Grey Fantail. This fact, coupled with the total lack of specimen records for Arnhem Land, has led to uncertainty about the status of these species in the region. Higgins & Peter (2002) concluded that both species were largely absent from Arnhem Land. The sole record of either species from northern Arnhem Land during *Atlas 1*, dated 1 July 1979, was from the edge of Melville Bay, 7 km south of Nhulunbuy (ALA #362045; Table 1), though there are no previous records from Gove Peninsula. Another record during *Atlas 1* (ALA #2196414; Blakers *et al.* 1984), from a site located 38 km southwest of Bulman, central Arnhem Land, presumably refers to the Grey Fantail (Figure 7) since the Mangrove Grey Fantail is confined to coastlines. Moreover, the record's date of 10 August 1977 is consistent with the species' status as a Dry season visitor to the Top End, presumably from southeastern Australia, where the migratory race *alisteri* breeds (Storr 1977; Higgins & Peter 2002). In the Darwin and Kakadu regions, it has been recorded mainly in monsoon rainforest and paperbark forest (Brooker & Parker 1985; Woinarski *et al.* 1988; McCrie & Noske 2015).

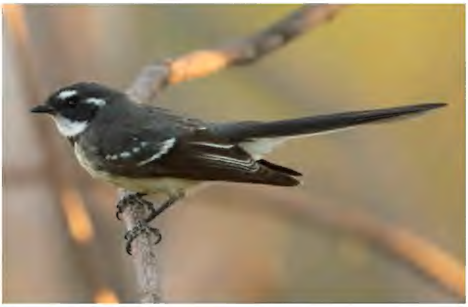


Figure 7. Grey Fantail (*Rhipidura albiscapa*), Katherine River. (Marc Gardner)

Between the two *Atlases*, the Grey Fantail was recorded twice in the Maningrida cell by J.C.Z. Woinarski, firstly 55 km SSW of Ramingining on 27 May 1987, and secondly just 5 km south of Ramingining on 1 August 1990 (ALA #1258989, and #1128818, respectively).

During *Atlas 2*, it was reported from the Nhulunbuy cell only, apparently the second record for Gove Peninsula (see above). Yet between 2011 and 2019, it was recorded no fewer than seven times from the Peninsula, five times in July, and once in June (Table 2). At Daliwuy (Table 2), the observer described the bird as having white along the full length of the tail and belonging to subspecies *Rhipidura albiscapa albicauda*. Given its coastal location and the lack of any confirmed records of this subspecies in the Top End, it is possible that this record refers instead to the Mangrove Grey Fantail, which has white along most of the length of the outermost tail feathers.

The sole record of the Grey Fantail from the study area between 2008 and 2018 was of two birds observed in a dense thicket of tall paperbarks beside Moremaker Billabong (Figure 1b), approx. 26 km WSW of Maningrida, on 23 July 2008 (R. Noske pers. obs.). Interestingly, the only record of the species from central Arnhem Land to date was from the old Goyder River Crossing, near Annie Creek, on 18 August 2016 (J. & P. Manins, S41888512).

Table 2. Records of Grey Fantail from northern Arnhem Land (sources: ALA 2020; eBird 2020). * denotes Fauna Atlas NT. # denotes eBird Australia. † denotes Birdata, BirdLife Australia.

Year	Date	Location	Latitude (S)	Longitude (E)	Observer
1979	1 July	Melville Bay	12°14'	136°45'	Unknown*
1984	30 April	Nhulunbuy	12°10'	136°46'	Wright, N.R.*
1987	27 May	–	12°45'	134°40'	Woinarski, J.*
1990	1 August	–	12°21'	134°54'	Woinarski, J.*
2011	17 July	Goanna Lagoon	12°13'	136°47'	Denmark, T.#
2014	30 July	Nhulunbuy	12°10'	136°46'	Unknown†
2016	19 July	Nhulunbuy Lagoon	12°10'	136°46'	Unknown†
2016	15 June	Daliwuy (Binydjarrna)	12°20'	136°55'	Rose, K.#
2019	12–15 July	Latram River	12°18'	136°46'	Rose, A. & S.#

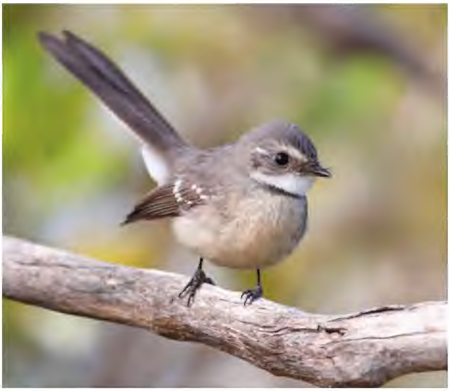


Figure 8. Mangrove Grey Fantail (*Rhipidura phasiana*), Mule Creek. (Marc Gardner)

While the Mangrove Grey Fantail (Figure 8) has an almost continuous coastal distribution in Western Australia from the Northern Territory border to as far south as Shark Bay (Johnstone & Storr 2004), its distribution in the Top End and northern Queensland appears to be highly fragmented. Higgins *et al.* (2006) considered that the species was absent from Arnhem Land, but I recorded it from Crab Creek, approx. 15 km east of Maningrida, on 28 September 2000 (Barrett *et al.* 2003; ALA #2071417), and it was still present at this site when we visited on 25 July

2008, 8 September 2009 and 10 December 2009 (R. Noske pers. obs.). A record from Marchinbar Island in the Wessel Islands group off northeast Arnhem Land on 18 April 2001 (ALA #2071025) must be questioned, given that Woinarski *et al.* (2001) did not record the species during a thorough survey of 62 of the Wessel and English Company Islands between July 1993 and October 1996. On the other hand, the somewhat similar Northern Fantail (*R. rufiventris*) was the fifth commonest bird species on these islands (Woinarski *et al.* 2001). Since 2009 the only records of the Mangrove Grey Fantail in Arnhem Land were from the mouth of Walker River (13°35'S, 135°50'E; B. MacDonald, S70586330) and Nungkanangka Island at the mouth of the Rose River, 1 km south of Numbulwar (M. Gardner, three records from 2017 to 2020), on the shores of the Gulf of Carpentaria in east-central and southeastern Arnhem Land, respectively.

GOULDIAN FINCH (*Chloebia gouldiae*)

Although originally described from specimens collected at Point Pearce, just south of present-day Wadeye, no fewer than 21 specimens of the Gouldian Finch (Figure 9) were allegedly collected from Port Essington, Cobourg Peninsula, between 1838 and 1849 (Fisher & Calaby 2009; Noske 2017). There have been no records from Cobourg Peninsula since 1849 (Frith & Hitchcock 1974), and indeed, there are few records from other coastal parts of the Top End. In November 1915, W. McLennan found small numbers (2–5) at a spring near his camp on the King River, and a flock of approx. 50 at another spring upstream (White 1917b). Humphries (1947) found the species in small

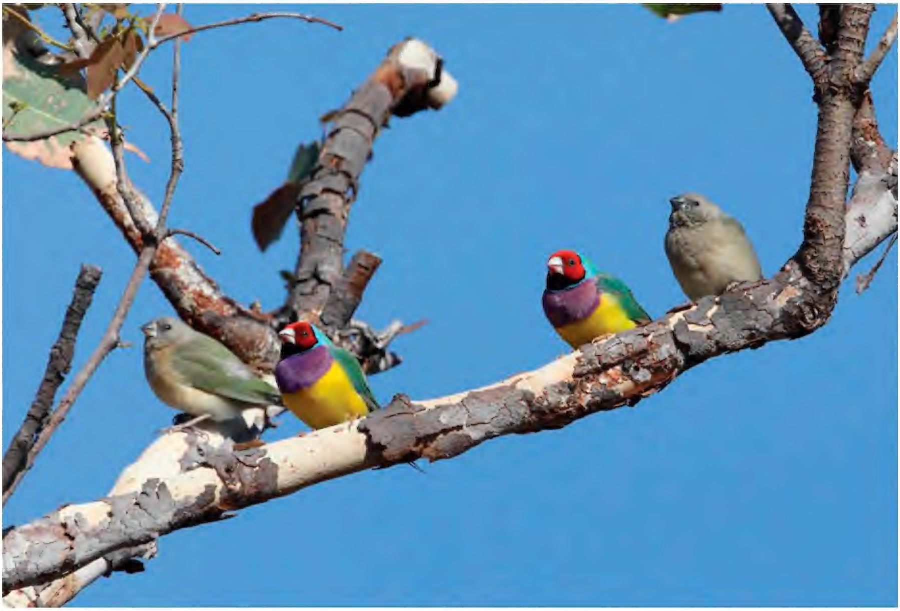


Figure 9. Gouldian Finches (*Chloebia gouldiae*). Adults and recently-fledged birds, Edith Falls. (Marc Gardner)

numbers on Gove Peninsula in 1944 and 1945, but there have been no subsequent records from northeastern Arnhem Land.

The Gouldian Finch was apparently first reported in the Maningrida cell from the Nangak floodplain, 6 km northwest of ABNL, on 27 April 1975 (D. Grace, ALA #432899), and 22 years later, from nearby Djinkarr Ranger Station on 16 November 1997 (K. Brennan, ALA #433407). During *Atlas 1* the species was allegedly encountered at a site approx. 25 km west of Maningrida, on both 30 November 1979 and 8 August 1978, though the site is approx. 18 km from the nearest site on the Upper Tomkinson floodplain, suggesting erroneous geographic co-ordinates. On 28 August 1980, it was reported from the "Old Arafura Homestead" though the co-ordinates are 8 km northwest of Murwangi (M. Reed, ALA #433072). In the Gunbalanya cell, it was reported from a site approx. 63 km east of Gunbalanya and approx. 70 km west of Maningrida on both 30 November 1977 and 8 August 1978 (ALA #433025, 331284).

More than three decades after they were last recorded there, approx. 40 Gouldian Finches were sighted on the Nangak floodplain during the first 'Bird Week' in July 2008. However, larger numbers were encountered on the Upper Tomkinson floodplain: 185 and 126 birds were counted on 23 July and 26 July, respectively (Table 1). The majority of birds (approx. 75%) were drably coloured juveniles. In addition, on 21 July, an adult pair with eight recently-fledged birds was seen and photographed in woodland dominated by Salmon Gum approx. 8 km south of the Kolorbidahdah turnoff. A flock of approx. 30 birds was still present on Nanguk floodplain on 18 October 2008 (pers. obs.) and an unknown number was reported approx. 10 km east of the Mann River crossing on 11 October 2008 (S. Randall, ALA #1294384).

In late June 2009, up to 25 birds were counted on Nangak floodplain, and 17 on the Upper Tomkinson floodplain, suggesting over 40 birds in total. Two months later (September 2009), approx. 50 juveniles with 10 adults, and six juveniles with three adults were seen in the former and latter areas (Table 1). In 2010, six adults were seen and photographed approx. 3 km WSW of the Kolorbidahbidah turnoff on 5 May, and 12 on 11 May (I. Davies pers. comm., S42449041), while at Nangak, up to 10 were seen in June and July. In 2011, only two birds were seen during 12 days in July, while in 2012 small numbers were seen in both July and October. From 2015 to 2018, none were recorded except in October 2016 (Table 1). In addition to these bird tour records, I recorded the species during censuses on the Upper Tomkinson floodplain on 19–20 October 2008 (2–30 birds at five sites), 9–10 May 2009 (1–2 birds at two sites), 26–28 August 2009 (1–60 at three sites) and on 7 December 2009 (approx. 20 at Nangak), but not in January 2009 or March 2010. Apart from those on the Nangak floodplain and on the Upper Tomkinson floodplain (2009–2010), the only eBird record from northern Arnhem Land refers to a site approx. 84 km southwest of Nhulunbuy (12°46'S, 136°17'E) on the Central Arnhem Road (T. Dolby, S16603218) on 9 March 2009.

Discussion

The present paper provides details of sightings of nine species of birds that were known from only a few localities in northern Arnhem Land prior to the instigation of the ABNL bird tours. Three of these species – Red Goshawk, Rufous Owl and Gouldian Finch (see below) – had been recorded during the early and/or late 1900s in both far western (i.e. Gunbalanya and King River) and far eastern (i.e. Gove Peninsula) Arnhem Land, so their occurrence in the intervening country is unsurprising. Nevertheless, the observations of nesting Red Goshawks in the Maningrida-ABNL area appear to represent the first confirmed breeding records for Arnhem Land.

The Hooded Parrot is known to breed in the Mann River catchment so its occurrence on the adjacent Tomkinson floodplain possibly represents post-breeding dispersal. The Nangak records of this species are closer to the coast than previously known localities, except for Banyan Island at the mouth of Woolen River, where it was reported during the 1940s. The 2019 eBird record from 37 km west of the Gapuwiyak turnoff on the Central Arnhem Road substantially extends the range of this species eastward to within 150 km of Nhulunbuy, although there have been no recent records from Gove Peninsula. Ignoring the undated *Atlas 1* record from the Gunbalanya cell, the species appears to inhabit subcoastal northern Arnhem Land over approx. 160 km from Mann River in the west to the abovementioned 2019 site on the Central Arnhem Road in the east. The almost total lack of records from central Arnhem Land suggests that this northern population may be isolated from populations to the south.

Prior to this study the Yellow-tinted Honeyeater was known within northern Arnhem Land only from the Gove Peninsula, where it is evidently scarce. Based on a broad-scale survey of riparian and adjacent non-riparian sites across the Top End during 1997–1998, and an analysis of a large distributional dataset, Woinarski *et al.* (2000) concluded that it was mainly associated with eucalypt-lined rivers in the southernmost lower rainfall (< 1,000 mm) areas, distant from river mouths. In their study, the species dropped out from higher rainfall areas where rainforest plants and paperbarks replaced eucalypts as the dominant component of the riparian vegetation. In striking contrast to those findings, it was found to be one of the commonest bird species in the paperbark woodlands of the Tomkinson River catchment, where it is a breeding resident. It was also common at Murwangi, approx. 66 km from the nearest site on the Upper Tomkinson floodplain, and eBird records since 2005 suggest that its subcoastal range extends at least 90 km eastwards to Gapuwiyak, though there are no recent records from the Nhulunbuy area.

Two of the remaining four species are known in the Top End mainly from the semi-arid interior. Hitherto unknown from the northern half of Arnhem Land, the Black-chinned Honeyeater population of the Tomkinson floodplain appears to be isolated; the nearest eBird record, near Annie Creek, being approx. 100 km to the southeast of the closest sightings on the Upper Tomkinson floodplain. The sightings of the Hooded Robins reported herein appear to constitute the first confirmed records for Arnhem Land.

The infrequency and small area of observations of this species suggest the population is very small and isolated, and therefore potentially at risk of local extinction. This is of particular concern given that the Tiwi Islands Hooded Robin (*Melanodryas cucullata melvillensis*), that was allegedly common in the early 1900s (Mathews 1914), is now Critically Endangered or possibly even extinct (Garnett *et al.* 2011).

The multiple records of Grey Fantails from Gove Peninsula, and single records from Moremaker Billabong and Goyder River Crossing substantially extend the known range of this migratory bird eastwards from Kakadu National Park. However, records of this species from the Gove Peninsula must be treated with caution in view of possible confusion with the Mangrove Grey Fantail, which has not yet been found there. Indeed, the apparent absence of the latter species from over 900 km of coastline between Maningrida and the Walker River mouth on the Gulf of Carpentaria is curious. Although restricted to mangroves, the Mangrove Grey Fantail is much less common in this habitat than the Northern Fantail, and in the Darwin region, it seems largely confined to the frequently inundated seaward edge of mangroves (McCrie & Noske 2015). Its presence at Crab Creek, near Maningrida, is consistent with this preference, as this site is a small mangrove-lined inlet on the coast of the Arafura Sea. In contrast, the species was not recorded in the tall mangroves that fringe the Tomkinson and Liverpool rivers, despite many hours of birding by boat from 2008 to 2018. The most extensive areas of mangroves in Arnhem Land occur between Ramingining and Arnhem Bay (135°30'E–136°30'E; Wightman 2006). Surveys of mangroves in this region may yet yield other sites where the species occurs.

The Gouldian Finch was recorded in five consecutive years, including all months from May (once) to early December, but not in January or March, suggesting that these birds moved away from the Tomkinson-Mann floodplain during the Wet season. This species undertakes regular seasonal shifts in habitat in response to seasonal changes in the availability of seeds of a variety of grass species (Dostine *et al.* 2001). At Yinberrie Hills near Katherine, it bred in hilly woodland during the Dry season, feeding mainly on the seeds of annual speargrass (*Sorghum* sp.), before moving to adjacent lowlands to feed on perennial grass species throughout much of the Wet season (Dostine *et al.* 2001). From mid-December to mid-February, these finches foraged mostly at sites within a radius of 10 km from the breeding area. Breeding at this site, and at Newry Station, near the Western Australian border, took place from February to August, peaking in April, but varied from year to year depending on the timing and amount of rainfall over the preceding Wet season (Tidemann & Woinarski 1994; Tidemann *et al.* 1999). The Tomkinson-Mann floodplain, however, lacked annual *Sorghum*, and instead supported a variety of other grass species such as *Eriachne burkittii, Pseudopogonatherum contortum, Heteropogon triticeus, Themeda triandra* and *Heterachne gulliveri*. The presence of up to 185 birds, mostly juveniles, throughout the Dry season in the study area suggests that these birds belonged to a colony or population that nested during the Wet season in the higher country to the south, dispersing to the floodplain in the Dry season after it had dried out. The sighting of recently-fledged dependent young from a late brood in late July 2008 in eucalypt woodland, approx. 26 km SSE of ABNL, indicates that this breeding colony may not be very distant from the study area.

Concluding remarks

Given the lack of ornithological exploration of Arnhem Land due to its remoteness from population centres and restricted access to visitors, it is hardly surprising that the bird tours and surveys reported herein have yielded some unexpected findings. Until these tours and surveys began in 2008, the only localities in western Arnhem Land that had been visited for extended periods were Gunbalanya, where collectors for two expeditions – one in 1948 and the other in 1968 – spent a combined total of nine weeks, and the King River, which W. McLennan explored over four months. Both of these localities were sampled mainly in the latter half of the Dry season. The only part of Arnhem Land to be sampled over a longer period is the Gove Peninsula, where Humphries and Boekel made casual observations over 15 and 10 months, respectively. The present study thereby represents the longest running, albeit not continuous, study of the mainland avifauna of Arnhem Land, and makes the Maningrida-ABNL region arguably the best-known. Nevertheless, many gaps still remain in our understanding of the distribution of birds across this large portion of the Top End of the Northern Territory, and there can be no doubt that other surprises await birders and scientists who visit Arnhem Land in the future.

Acknowledgements

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Appendix 1. Geographical co-ordinates (to nearest minute) of localities mentioned in the text, determined by the author using Google Earth unless source is marked with an asterisk.

Location	Co-ordinates	Reference
Arnhem Land Barramundi Lodge	12°12'S, 134°17'E	Present study
Annie Creek	13°02'S, 134°56'E	Robinson *et al.* (1992)*
Arafura homestead	12°27'S, 134°55'E	Reed and Tidemann (1994)*
Banyan Island	12°15'S, 135°14'E	Higgins (1999)
Crab Creek	12°03'S, 134°22'E	Present study
King River camp	11°53'S, 133°29'E	White (1917b)
Kolorbidahbidah turnoff	12°20'S, 134°22'E	Present study
Mann River	12°19'S, 134°05'E	Reed and Tidemann (1994)*
Mann River crossing	12°21'S, 134°08'E	Present study
Moremaker Billabong	12°15'S, 134°06'E	Present study
Murwangi Safari Camp	12°29'S, 134°58'E	Present study

Red flags in a sea of green

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Abstract

This article covers the author's experiences over many years, with invertebrates in general and with the spectacular and enigmatic Leichhardt's Grasshopper (*Petasida ephippigera*) (Orthoptera: Pyrgomorphidae) in particular. It recalls her initial introduction to CSIRO, then employment with this organisation in Kakadu National Park, then 'falling for' *Petasida ephippigera*, and finally her own studies on it at Davidson's Arnhem Land Safaris on the Cooper Creek system at Mount Borradaile. Many questions flow on from these initial observations, particularly the relationship between this insect and fire.

Introduction and history of discovery

Looking back over close to 30 years, it feels like we are now living through another period of 'lost knowledge' and intergenerational change, similar to that of the 1900s when Leichhardt's Grasshoppers went unseen for some 70 years. From 1991 onwards, many of the staff from Parks Australia North retired, moved onto other departments or took on other areas of interest. And the same holds true for scientific researchers. Therefore, currently, long-term memory and prior knowledge of this special species of grasshopper that forms the subject of this article and its habitat are at risk of being lost. Aboriginal elders have passed away and younger Aboriginal people might have lost or forgotten once widespread knowledge – as was noted by Ngukurr/Yugul Mangi Rangers of southeastern Arnhem Land who, on 20 January 2015, asked the researchers who were accompanying them: "Who or what are these grasshoppers?".

The adjective 'spectacular' comes to mind when describing the colouration of the Leichhardt's Grasshopper (*Petasida ephippigera*) (hereafter simply "the Grasshopper(s)"). Adults have a black and orange-red body, wings and legs, alternating dark and light antennal segments, and an orange-red and bright blue head and pronotum (Morris 1996; Holbery 2011; O'Dea 2014; McKay 2015). Adult females (measuring 60 mm) are larger than adult males (measuring 45 mm) (pers. obs.). I like to think of these strikingly coloured Grasshoppers as 'Little red flags in a sea of green' in the sandstone country of Arnhem Land. *Petasida ephippigera* is easily seen on its principal host plant, the lamiacean *Pityrodia jamesii, a* perennial mid-green coloured aromatic shrub with a sage-mint odour when crushed.

When handled, the Grasshoppers often exude a brown sticky liquid, like tobacco juice, from the mouthparts as a chemical defence (Fletcher *et al.* 2000). On one occasion I

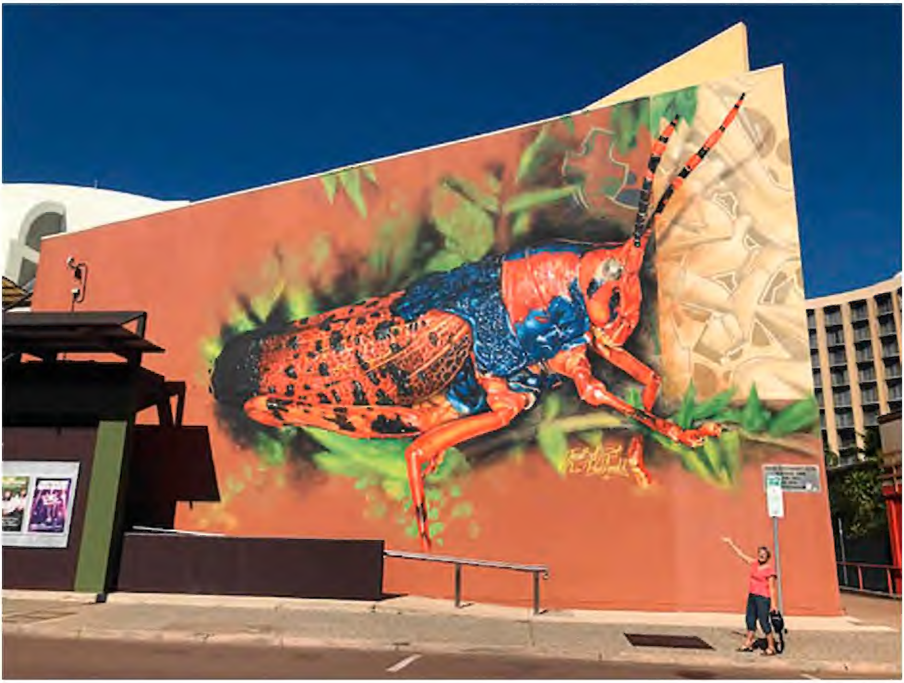

Figure 1. Leichhardt's Grasshopper, a 'Street Art' wall painting by Jesse Bell on the exterior of the Darwin Entertainment Centre, Mitchell Street, Darwin. November 2019. Reproduced with the artist's permission. (Photograph by Paul Arnold)

decided to taste the liquid myself, as a Scottish scientist suggested "you have to eat your study animal at least once". I don't remember the liquid being distasteful and am still around to tell the tale. The website for Kakadu National Park suggests: "the grasshoppers secrete a smelly brown substance that tastes awful to any animals looking for a snack" and Fletcher *et al.* (2000) suggest the Grasshoppers are rich in terpene glycosides, which are non-toxic but known to be bitter tasting. There seems to be no mammalian predators, although I have seen an adult female green praying mantid eating the Grasshopper from the head-end.

Adult males and females aggregate together. Copulating animals can be observed in 'piggy-back' position, which can continue for 24 hours. This long copulation is thought to eliminate insemination by other males (David Rentz pers. comm.).

The nearest relative of *Petasida ephippigera* (the sole species in the genus) is *Scutillya verrucosa* (another monogeneric species) which is found in the heathlands of southwestern Western Australia. Both these species are in the tribe Petasidini, but isolated from each other.

A question which exercises my mind: "Is Africa a possible epicentre of the Pyrgomorphidae?" If so, how did these two Australian species come to be so widely separated – by approximately 2000 kilometres? I jokingly suggest that *Petasida* jumped aboard a northward-floating Australia after the breakup of Gondwana. *Scutillya* jumped aboard a little later. Or were they both already on that portion of the continent which floated away and became separated by desert as the continent dried? Key (1985) hypothesises that *Petasida* and *Scutillya* may have had a common ancestor in Poekilocerini (another tribe in the subfamily Pyrgomorphinae), as throughout the Cretaceous geological period Western Australia and India were in contact or near contact.

As the common name Leichhardt's Grasshopper suggests, the specimens collected by the explorer Ludwig Leichhardt were the second in a series of collections made in northern Australia in the 1840s. Leichhardt collected them on 17 November 1845 to be exact, at Deaf Adder Creek in the headwaters of the South Alligator River – now within Kakadu National Park. Imagine the scene; storms brewing over the Arnhem Land plateau, and thunder and lightning strikes [Normand (2017) describes the idea of "a pale skinned travelling Ceremony Man carrying a spear which shot lightning"]. No wonder the Aboriginal people mistook Leichhardt for *Namarrkon* the Lightning Man. Gundjeihmi speakers call the Grasshoppers *Alyurr* and believe they are the children of *Namarrkon* the Lightning Man; a powerful creator ancestor/being. *Alyurr* call out to their father who answers with storms and lightning when clinking his stone axes (Chaloupka 1993).

Another perspective comes from a quote by Leichhardt himself: "Whilst on expedition we observed a great number of grasshoppers, of a bright brick colour dotted with blue, the posterior part of the corselet, and the wings were blue, it was two inches long, and its antennae three quarters of an inch" (Leichhardt 1847).

The three initial/early collections were:

- By purser John Dring aboard HMS *Beagle* during Matthew Flinders' circumnavigation and mapping of the Australian coast between 1837 and 1843. The *Beagle* travelled 260 km along the Victoria River. The holotype (a female specimen) was taken to London, described by White in 1845, and deposited in the British Museum of Natural History in London.
- By Ludwig Leichhardt at Deaf Adder Creek headwaters on 17 November 1845 as mentioned above.
- The third collection was made during the A.C. Gregory expedition of 1855–1856 at a site very close to the present day township of Timber Creek (Calaby & Key 1973). The Gregory expedition set out to find Leichhardt, who had disappeared on an earlier inland expedition.

There were no further collections for well over 100 years until mining activities and pastoralism commenced in Arnhem Land. Although the Grasshoppers are obvious in the Wet season, they went unrecorded due to limited accessibility of the country.

Early in 1970, Aboriginal people from Milingimbi approached Bob (R.L.) Collins, a Technical Officer with CSIRO. [Bob later become Member of the Legislative Assembly of the Northern Territory after Self Government in 1978.] They had in excess of 20 live Grasshoppers and they asked Bob: "Who or what are these?" Bob sent the specimens to CSIRO (Australian National Insect Collection, hereafter ANIC) in Canberra. They were fed a diet of lettuce (as little was known of their food plants). After they died they were curated and deposited in the ANIC collection.

Anecdotal evidence from Tony Press (pers. comm.) [Director of Parks Australia North] early in 2000 suggests there was an "explosion" of populations of the Grasshopper on the sandstone escarpment at Spring Creek where there were thousands eating themselves out of "house and home" until no vegetative parts remained on the host plants.

The lack of collections and sightings of the Grasshoppers seems relevant to the present time, where our 'working life' span comes to an end. Knowledgeable and experienced people transfer to other government departments, or even states, as they retire or move away from the Northern Territory. So, with a lack of management interest and funds, as well as the passing of Aboriginal elders, knowledge is not being passed on and becomes lost altogether.

My interest in the Grasshoppers

My interest piqued when I was working for the CSIRO. Dr David Rentz [Curator of Orthoptera at ANIC] visited the Tropical Ecosystems Research Centre, which was part of CSIRO in Darwin, in 1991 to study the orthopteran collection. He suggested a visit to Kakadu National Park to locate the Grasshoppers. We visited but did not find any of them. I revisited the Park regularly over the following year, and in January 1992 I came across 19 individuals close to Baroalba Springs carpark.

During the years 1992–1994 I observed the Grasshoppers along the Baroalba Springs Road, Koongarra Saddle and Little Nourlangie Rock, all within Kakadu National Park. Fire was a threat to people and Park assets, as well as the Grasshoppers. If they survived fire, but their food plant was burnt, then what? If they died, then there was no reproductive event. This fate of 'death by fire' also happened in other areas of the Northern Territory. Or did they all die? Perhaps their eggs persisted underground like other invertebrates. Or did juveniles drop to the ground ahead of the fire? Or did the adults fly ahead of the fire?

I was unsuccessful in obtaining a Research Permit from Parks Australia North to investigate these questions, but in April 1995 I met Max Davidson of Davidson's Arnhem Land Safaris. The Davidson's safari camp was on a leased area along the Cooper Creek system at Mount Borradaile, 55 km north of Kakadu National Park in western Arnhem Land. Max offered me support in the form of accommodation, food and transport (in an old-style Toyota open back safari wagon). During a trip to the camp with a Japanese film crew late in 1999, he and I discussed the possibility of an observational study. Max was concerned about the survival of the Grasshoppers on his lease, noting the populations were in decline. Our observations began with a visit to the camp to walk the lease and find the Grasshoppers and their habitat. The Grasshoppers are one of many (tourist) attractions at the camp (and in the Northern Territory in general) and we agreed to proceed with our study. Our observations were initiated in January 2000 and the last survey was in March 2005. A traditional owner of his mother's country – Mount Borradaile area – visited the camp frequently and was in attendance during discussions. The areas where we found the Grasshoppers included the causeway, the paperbark beds, the swimming hole sand sheet, the white stone line trail (north of the camp), and others. I visited regularly every five to six weeks for three to five days at a time. All the grasshoppers we located were counted (Queen Bee Labels were used to tag them initially, but were ultimately unsuccessful), as well as the *Pityrodia jamesii* shrubs on which they were living.

Adult male and female Grasshoppers were distinguishable and sedentary; they were observed to remain on their host plant for their entire life. Sometimes they were easily disturbed and responded, as do Frilled-neck lizards (*Chlamydosaurus kingii*), by creeping to the other side of the stem from the observer – a typical avoidance behaviour.

The Grasshoppers; juvenile and adult

Early in the study at Mount Borradaile I thought the Grasshoppers hatched after the first rains of the Wet season. However, hatching is now thought to be irregular and variable. Recently, Peter Holbery [a local naturalist] has suggested that hatching of the Grasshoppers has become more variable and juveniles are found in May to November. He has suggested that above-average rainfall and a pronounced Wet season could result in a longer growing season for the food plants and this, in turn, might be resulting in better quality nutrition, thus enabling the Grasshoppers to mature earlier than usual (Holbery 2011).

Juveniles hatch early in the oncoming Dry season and measure approx. 10 mm in length; their colouration is pale green with black spots on the body and alternating pale and black antennal segments. When viewed against the apical tips of the host plant, the alternating segments of the antennae are easily seen, but they are well camouflaged in profile. Juveniles transform from one instar to the next and the colours gradually darken. Barrow (2009) observed the nymphs are elaborately patterned but cryptic, and Rentz (1996) suggested there are six or seven instars (moults) before maturity. The spectacular colouration is most obvious at the last two instars with the appearance of wing buds.

I found that females carry 80 or more eggs. Barrow (2009) found the eggs of the Grasshoppers are laid in wet sand below the host plants and within 2.5 cm of the soil surface.

As adults age, their wings become tatty or break. They die, and may get hung up in the twigs of *Pityrodia jamesii,* where they are consumed by ants.

Where are the Grasshoppers found?

The Grasshoppers are known to occur in scattered localities north of 16°S in western and northern Arnhem Land and the eastern Kimberley-western Victoria River District (Calaby & Key 1973; Lowe 1995; Wilson *et al.* 2003; ALA 2020). Within this range they have been found in Nitmiluk National Park, where I encouraged further study by rangers by forwarding a Research Plan and data sheet. They are also found in Keep River National Park, but those individuals appear paler than those further east. Anecdotal evidence includes occurrences in areas on the mainland adjacent to the Wessel Islands off the eastern Arnhem Land coast, and at Bulman. Local fishermen suggest they occur also at the Fitzmaurice River mouth along the Northern Territory coast (pers. comm. to author by an officer of Northern Territory Police at Timber Creek Police Station 1994).

Fire has changed the habitat. In February 2014 I was invited to participate in a survey of the Grasshoppers conducted by rangers and Aboriginal family members at a site near the Bowali Visitor Centre at Kakadu National Park Ranger Headquarters. Numerous adults were observed on recently burnt, low vegetation and within sight of the escarpment. I commented to a ranger that "the vegetation had thinned remarkably" since the days of my initial visits in 1991, wherein the escarpment walls were unable to be seen through the thick vegetation. The ranger was unaware of the thinning, and looked worried as he spoke. In 1994, along the road to Baroalba Springs, the previously dense vegetation was heavily impacted by fire, following years of burning by Parks and Wildlife to prevent late season hot fires burning into Kakadu National Park from Bulman in the south. Incendiaries were dropped from helicopters onto the sandstone escarpment country and the resulting fires burned for weeks at a time – on two occasions in excess of two weeks.

Host plants

Pityrodia is an Australian endemic genus of lamiacean plants of Gondwanan origin (Specht 2012). *Pityrodia* was first described by Robert Brown in 1810 while on Matthew Flinders' circumnavigation of the Australian coast. *Pityrodia jamesii* is the host to the Grasshoppers at Mount Borradaile and other areas within Kakadu National Park. The type specimen of *Pityrodia jamesii* was collected during the 1948–1951 American-Australian Scientific Expedition to Arnhem Land. The plant is endemic to the Northern Territory, and occurs widely in the East and South Alligator Rivers region.

Interestingly, Holbery (2011) claimed that all developmental stages of the Grasshoppers were more often found on less vigorous plants of *Pityrodia jamesii*. Vigorously-growing food plants appear to be avoided (Holbery 2011).

Dampieria conospermoides was one of the host plants on which the Grasshoppers were found during the American-Australian expedition, as well other species of *Pityrodia*. A species of native *Gardenia* is also recorded as a food plant (Key 1985). In Nitmiluk National Park the host plant is *P. pungens*, but in Keep River National Park it is *P. ternifolia* (Wilson *et al.* 2003).

Some years ago the Territory Wildlife Park at Berry Springs near Darwin had proposed an invertebrate display that included the Grasshoppers. However, the Park was unsuccessful in propagating the host plant, thus making it difficult to keep the Grasshoppers in captivity. I have had similar difficulty when trying to grow the host plant.

Fire

Fire is a common occurrence in the sandstone heath country in the Top End of the Northern Territory and *Pityrodia* is an aromatic plant which burns readily. However it regenerates quickly from root stock and grows to approximately 6 or 7 cm within three weeks. In the early years of my interest in the Grasshopper, I observed late Dry season fires burn in, and around, Nourlangie Rock for many weeks. So I wondered how populations of this insect reacted to fire. One possibility is that individuals could fly out of range of the advancing flames (I observed a flight of more than 100 m by adults at Mount Borradaile). Another possibility is that individuals sit atop the host plants as fire/smoke draws near and then fall to the ground taking refuge under rocks before the fire strikes. During the Kapalga Fire Experiment I observed many other (different) species of grasshoppers flying ahead of the fire, and crickets and other readily mobile invertebrates racing up tree trunks well in advance of fire fronts, and certainly well before awareness of the impending fire by humans. Maybe the Grasshoppers possess this fire sense too?

What do the Grasshoppers feed on after a fire? And do they escape burnt areas and feed on other resources? Or do they starve and die? I observed that after a fire near Baroalba Springs, juveniles feed on the furry bark of dead/burnt *Pityrodia* plants, and Barrow (2009) made similar observations. While the plants themselves regenerate from the root stock, their seeds have dropped onto sandstone rock surfaces and, following Wet season monsoon rains, they are funnelled by flowing water between rocks and drainage lines where nutrients accumulate. I have seen germination by seeds that were caught up amongst fire debris.

During repeat visits to sites in the early years of the Mount Borradaile study I noticed that Grasshoppers rarely hatched out at the same sites on consecutive seasons, and Barrow (2009) in his study recorded only one site at which their eggs hatched on two consecutive years. Early in my 'orthopteran career' David Rentz mentioned that the eggs of the Grasshoppers might remain viable underground for seven to 10 years. So perhaps the soil could insulate the eggs at this depth provided their viability remained intact (pers. obs. based on observations made during CSIRO's Kapalga Fire Experiment in 1995).

Grimaldi & Engel (2005) suggest cicadas have existed for between 40 and 200 million years; so is it possible these pyrgomorphs had a similar life history initially? Is it possible that the Grasshopper pre-dates the breakup of Gondwana and the strategy of having eggs that remain underground might be an adaptation to unpredictable, fluctuating climatic conditions or environmental uncertainty? Later Aboriginal burning practices and contemporary European burning practices using incendiaries might also have impacted populations. Barrow (2009) reminds us that the Grasshopper certainly pre-dates Aboriginal burning practices.

Through this process of writing it seems clear to me now that David Rentz may have harboured these thoughts and questions long ago, but at that time I had not 'connected the dots' to understand these connections.

Acknowledgements

I am grateful to David Rentz for instigating my voyage of discovery on this fascinating insect. I hope that my experiences and reflections will stimulate readers' interest in this ancient animal and landscape. I must also thank the late Max and Phillipa Davidson for their generous support of the project at Mount Borradaile. This article was one of a series of essays written for a museum exhibition by Melbourne-based artist Simon Normand on Ludwig Leichhardt that was planned to be published in 2020, but unfortunately COVID-19 took care of that. Simon describes the exhibition as being in a "comatose" state now so he generously agreed that I publish the essay as an article in *Northern Territory Naturalist* to stimulate discussion on the content and the questions posed. I am very grateful to him for this agreement. Jesse Bell has approved the reproduction of his artwork. In the Northern Territory, the 2021 Wet season is underway as are the adult Grasshoppers, so it is a very opportune time to publish this article.

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What to grow: An annotated list of native larval food plants of butterflies and diurnal moths in the Darwin region, Northern Territory

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Abstract

An annotated list of native larval food plants (131 species) of butterflies and diurnal moths (92 species) is provided for the Darwin region. We also collate information on the broad habitat, life form, plant part eaten, and method of cultivation for each species of food plant. Mistletoes, shrubs, herbs and grasses are predominately used in savannah woodland, whereas trees and vines are mainly exploited in monsoon vine forest and semi-deciduous monsoon vine thicket. All plant parts are eaten, but larvae of most species feed on leaves or the soft, new growth of young leaves. While the larvae of most butterflies/diurnal moths feed on several plant species, at least 26 species are known, or suspected, to feed only on a single species of native plant in the Darwin region. The compilation of such a list of indigenous food plants is to encourage further establishment of these species, particularly in suburban gardens, parks and roadside verges, to attract local butterflies and diurnal moths, thereby enhancing insect biodiversity in the urban landscape.

Introduction

A recent analysis of the distribution of butterflies and diurnal moths of northern Australia (excluding Cape York Peninsula) identified the northwestern corner of the Top End as a biodiversity hotspot for this group of insects (Braby *et al.* 2020b). It is estimated that 120–122 species of butterflies/diurnal moths occur in the inner and outer conservation reserves of Darwin (i.e. within 60 km of the CBD) according to range-map data based on a recently published set of spatial distribution maps (Braby *et al.* 2018). Given this substantial diversity of Lepidoptera, and the strong interest in natural history, entomology (especially butterflies) and biodiversity conservation by the local community in the Darwin region, it is considered desirable to summarise the native plants exploited by this group of insects for this area. However, there is no readily available list of native plants used by species of butterflies and diurnal moths inhabiting just the Darwin region. Knowledge of which lepidopteran species feed on which species of plant has obvious practical benefits in terms of restoration ecology and landscape rehabilitation, as well as augmentation of conservation reserves, nature parks, suburban gardens and rural properties (i.e. green space) to sustain insect diversity in the wider urban landscape.

The purpose of this article is to collate information on the native larval food plants used by butterflies and diurnal moths inhabiting the wider Darwin region (i.e. within c. 60 km of the Central Business District). Such a list of food plants may encourage local residents, non-government organisations and local councils to propagate and establish these species, particularly in suburban gardens, parks and roadside verges, to attract local butterflies and diurnal moths, thereby enhancing insect biodiversity in the urban landscape. These plants may also be useful in ecological restoration of degraded landscapes because the ecological interactions between butterflies/diurnal moths and their host plants contributes to overall ecosystem function (Lomov *et al.* 2006).

It should be noted that the larvae of several butterflies also feed on introduced or exotic plants in the Darwin region and the Top End more widely. Over 40 species of non-native plants have been recorded as larval food plants for 34 species of butterflies and diurnal moths in northern Australia (see Braby *et al.* 2018 for a more detailed compilation of the species involved). In most cases, these plants serve as supplementary dietary food items and, as far as we are aware, there is no species of butterfly or diurnal moth that is reliant on them for survival. In this article we have not included introduced species because we do not wish to promote such plants, particularly those that provide little ecological benefit for other organisms or comprise invasive weeds that threaten biodiversity. As examples, Pale-orange Darter (*Telicota colon*) is known to use Gamba Grass (*Andropogon gayanus*), and four butterflies (Yellow Swift (*Borbo impar*), Lyell's Swift (*Pelopidas lyelli*), No-brand Grass-dart (*Taractrocera ina*) and Evening Brown (*Melanitis leda*)) readily use Annual Mission Grass (*Cenchrus pedicellatus*) (Braby *et al.* 2018). On the other hand, the Pale Triangle (*Graphium eurypylus*) often uses the Indian Mast Tree (*Monoon longifolium*), which is cultivated as an ornamental street tree around Darwin, but it also uses a suite of native plants in the family Annonaceae.

Methods

The list of plants of the Darwin region was based primarily on the review of butterfly food plants in the monsoon tropics of northern Australia by Braby *et al.* (2018, Appendix I). More detailed compilations of butterfly food plants can be found in Meyer (1996) and Braby (2011, 2015). Most of the plant-butterfly/diurnal moth associations were extracted for the Darwin region. However, in some cases records outside this geographical area were included if: (1) the species of butterfly/diurnal moth definitely occurs in the Darwin region, (2) the species of plant is known to occur within the Darwin region, and (3) it was considered highly likely that the plant species would be used as a food plant by the lepidopteran species in that part of the range. For example, the Narrow-winged Awl (*Badamia exclamationis*) occurs frequently in the Darwin region during its annual migration and it appears to be a seasonal immigrant to the area (Braby *et al.* 2018). The only known food plant of this butterfly in northern Australia, Damson (*Terminalia microcarpa*), occurs in Darwin where it is restricted to monsoon vine forest. However, *T. microcarpa* has not been recorded as a food plant for *B. exclamationis* in Darwin, but it has been recorded for this species in the eastern Kimberley of Western Australia near Kununurra (Meyer 1996). Therefore, if *B. exclamationis* breeds in the Darwin region, then *T. microcarpa* is the most likely larval food plant.

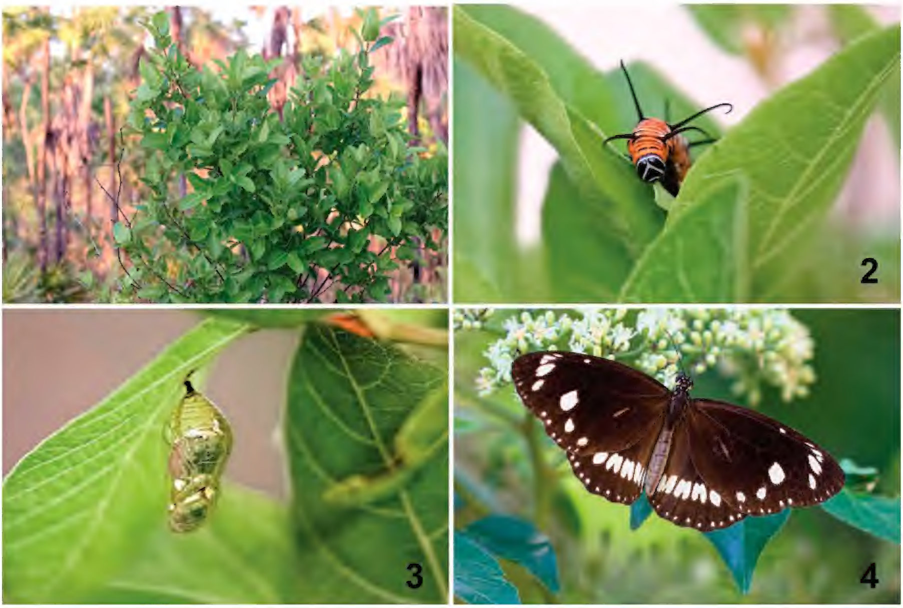
We also collated information on the life form of the food plant, noting the habit of each species as palm, tree, shrub, vine, herb, grass, sedge or mistletoe. For the plant part eaten, we distinguished nine categories as follows: leaf, young new leaf growth, flower bud, flower, fruit, seed, woody stem, photosynthetic vine, and root. Information on propagation for each plant species where known was obtained from Brock (2001), Fern (2014), ANPSA (2020) or made by inference from congeners or other closely related species.

The food plants for the Darwin region were then assigned to one (or more) of four categories according to the broad vegetation community in which each plant most commonly occurs: (1) savannah woodland; (2) monsoon vine forest and semi-deciduous monsoon vine thicket; (3) paperbark woodland/swampland associated with freshwater floodplains; and (4) mangrove and saltmarsh associated with saltwater. The reason for this distinction is that each of these broad vegetation communities are generally comprised of a suite of plants characteristic of that environment, with only minor overlap in species composition. Accordingly, it follows that the butterfly/diurnal moth assemblage of these habitats are also quite distinct, although some species do occur in more than one vegetation community. For example, the pierids Large Grass-yellow (*Eurema hecabe*) and Scalloped Grass-yellow (*Eurema alitha*) and the lycaenids Northern Pencil-blue (*Eirmocides margarita gilberti*), Small Dusky-blue (*Erina erina*), Black-spotted Flash (*Hypolycaena phorbas*) and Purple Cerulean (*Jamides phaseli*) breed in both monsoon vine thicket and savannah woodland, often on the same species of plant in each of these habitats.

Nomenclature for the butterflies and diurnal moths follows Braby *et al.* (2018) and two recent papers (Braby *et al.* 2020a; Hsu 2020), while that for the plants follows the Northern Territory Herbarium (Cowie *et al.* 2017).

Results and Discussion

An annotated list of larval food plants exploited by butterflies and diurnal moths in the Darwin region is presented in Appendix 1. We stress, however, that this list is provisional and by no means complete. For example, Tissa Ratnayeke (pers. comm.) recently recorded larvae of the Common Crow (*Euploea corinna*) feeding on *Ficus aculeata* at Holmes Jungle Nature Park (Figures 1–4), a plant species that was previously not known to be used by this butterfly.



Figures 1–4. The Common Crow (*Euploea corinna*) and one of its larval food plants at Holmes Jungle Nature Park, Darwin: (1) *Ficus aculeata*, (2) larva, (3) pupa, and (4) adult butterfly. This species of fig was previously not known to be used by this species of butterfly. (Tissa Ratneyeke)

Moreover, there are several species of butterflies and diurnal moths in the Darwin region for which there are no documented records of their food plants. Good examples of species with unknown or poorly documented food plant associations are the Poaceae-feeding skippers (e.g. Spotted Grass-skipper (*Neohesperilla senta*), Narrow-brand Grass-skipper (*N. crocea*), Yellow Grass-skipper (*N. xanthomerra*), River Sand Grass-dart (*Taractrocera dolon diomedes*), Green Grass-dart (*Ocybadistes walkeri olivia*), White-margined Grass-dart (*O. hypomeloma*), Narrow-brand Grass-dart (*O. flavovittatus vesta*), and Wide-brand Grass-dart (*Suniana sunias sauda*)), some of the smaller blues (e.g. Glistening Line-blue (*Sahulana scintillata*), Common Grass-blue (*Zizina otis*), Dainty Grass-blue (*Zizula hylax*), and Orange-tipped Pea-blue (*Everes lacturnus*)) and several agaristine moths (e.g. Pale Banded Day-moth (*Leucogonia cosmopis*), Laced Day-moth (*Ipanica cornigera*), Indigo Day-moth (*Idalima leonora*) and Central Spotted Day-moth (*Mimeusemia centralis*)). The food plants for most of these species are well documented from other areas of their range, such as northeastern and southeastern Queensland (Braby 2000; Moss 2019), but the actual species involved for the Top End have not been recorded. In other words, although knowledge of the butterfly/diurnal moth-plant associations is reasonably complete there is still much to learn about the food plant preferences for the Northern Territory.

In other cases, species recorded from the Darwin region are possibly vagrants to the area and do not breed within the region. For example, both the Purple Beak (*Libythea geoffroyi genia*) and Orange Tiger (*Danaus genutia alexis*) have very occasionally been recorded from the Darwin region (Meyer *et al.* 2006; Braby *et al.* 2018). However, the known larval food plants for these butterflies – *Celtis strychnoides* (Braby 2014) and *Oxystelma esculentum* (Meyer 1995), respectively – do not occur in the Darwin region, indicating that either breeding populations of these butterflies are not permanently established or, if they are established, they breed on alternative (as yet unreported) food plants.

Overall, we estimate that at least 131 species of native plants are used, or potentially used, by 92 species of butterflies/diurnal moths in this area (Appendix 1). At least 75 species of native plants are known to be used in savannah woodland (by 60 species of butterflies/diurnal moths), whereas fewer food plants are recorded from paperbark woodland/swampland (18 species) and mangrove/saltmarsh (9 species) (by a total of 26 species of butterflies/diurnal moths) (Table 1). Monsoon forest/vine thicket habitats support an intermediate number of species, with a total of 49 species of plants known to be used (by 44 species of butterflies/diurnal moths), including those that breed only along the edge or ecotone of the habitat. Some species like Fiery Jewel (*Hypochrysops ignitus erythrina*) frequently use at least four monsoon forest tree species (e.g. *Alphitonia excelsa*, *Clerodendrum floribundum*, *Glochidion apodogynum*, and *Maranthes corymbosa*), but only when they are saplings growing in savannah woodland or along the margins of monsoon forest/vine thicket.

The larval food plants utilised include all life forms, but mistletoes, shrubs, herbs and grasses predominate in savannah woodland, whereas trees and vines are mainly exploited in monsoon forest/vine thicket (Table 1), which reflects the different prevalence of those life forms in savannah and monsoon forest. All plant parts are eaten, but larvae

Table 1. Number of larval food plant species exploited by butterflies and diurnal moths in the Darwin region for each major habitat according to plant life form. For plants that occur in more than one habitat, the species are tallied for each habitat. Percentages refer to proportional representation of each life form among the four habitats. Data are based on the list presented in Appendix 1.

Life form	**Savannah woodland**	**Monsoon forest/ vine thicket**	**Paperbark woodland/ swampland**	**Mangrove/ saltmarsh**	**Total**
Palm	1 (33.3%)	1 (33.3%)	1 (33.3%)	0	3
Tree	7 (22.6%)	19 (61.3%)	2 (6.4%)	3 (9.7%)	31
Shrub	24 (68.5%)	8 (22.9%)	3 (8.6%)	0	35
Vine	13 (36.1%)	16 (44.4%)	5 (13.9%)	2 (5.6%)	36
Herb	12 (66.7%)	1 (5.5%)	2 (11.1%)	3 (16.7%)	18
Grass	9 (64.3%)	1 (7.1%)	4 (28.6%)	0	14
Sedge	1 (33.3%)	1 (33.3%)	1 (33.3%)	0	3
Mistletoe	8 (72.7%)	2 (18.2%)	0	1 (9.1%)	11
Total	**75**	**49**	**18**	**9**	

of most species feed on leaves or the soft, new growth of young leaves. Flower buds and flowers are only exploited by certain species of Lycaenidae (blues). Fruits, seeds, wood and roots are rarely used – only single species are known to specialise on each of fruits (by Princess Flash (*Deudorix smilis*)) and woody tissue (by Clearwing Moth (*Pseudosesia oberthuri*)), whereas the roots of the grass *Chrysopogon latifolius* support an extensive rhizomatous mat that is eaten by the larvae of Northern White-spotted Sun-moth (*Synemon phaeoptila*).

In addition, the age or height of the plant is important for some species. For example, Wattle Blue (*Theclinesthes miskini*) and Fiery Jewel (*Hypochrysops ignitus*) only feed on the sapling stage of their host plants, many individuals of which typically grow into trees. Clearing Moth (*Pseudosesia oberthuri*) feeds on seasonal perennial vines of *Ampelocissus* (several species) but only once they have matured and developed vigorous woody stems. Conversely, many species which feed on trees will also use the same plant species when they are saplings or shrubs. For examples, Ornate Dusk-flat (*Chaetocneme denitza*), of which the larvae feed on the mature leaves of Cocky Apple (*Planchonia careya*), and Chrome Awl (*Hasora chromus*), of which the larvae feed on the soft, new growth of young leaves of Pongamia (*Millettia pinnata*), will utilise tree, sapling/shrub growth forms regardless of height.

Some species of plants are exploited by many butterflies and diurnal moths. The mistletoes *Decaisnina signata*, *Amyema sanguinea*, *A. bifurcata*, *A. miquelii*, *A. villiflora*, *Dendrophthoe glabrescens* and *Dendrophthoe odontocalyx* each support three for more species of butterflies/diurnal moths. Collectively, these plants provide food for a total of nine species, highlighting the importance of mistletoes as a keystone resource in the landscape (Watson 2001; Anderson & Braby 2009). The monsoon forest/vine thicket trees Coastal Tuckeroo (*Cupaniopsis anacardioides*) and *Millettia pinnata* are particularly important, each being used by five species of butterflies, as is the vine/shrub *Capparis sepiaria* with three, and possibly, four species. The grasses *Imperata cylindrica* and *Ischaemum australe* are each used by four species of butterflies, and the vine *Cynanchum carnosum* is used by three species of danaine butterflies. The vine *Ampelocissus acetosa* and related shrub *A. frutescens* provide food for three species of diurnal moths.

A mix of native plant species is desirable to attract a large diversity of butterfly/diurnal moth species. While some species, such as *Cupaniopsis anacardioides*, *Millettia pinnata*, *Capparis sepiaria*, *Imperata cylindrica* and *Ischaemum australe*, provide food for many species, it is important to consider that a number of species of butterflies and diurnal moths in the Darwin region utilise only a single species of food plant (i.e. are monophagous) or a very narrow range of plant species, such as a few species in the same genus or a few genera in the same family. For example, the following trees are the only known food plants for five species of butterflies and diurnal moths: *Carallia brachiata* (for Six O'clock Moth (*Dysphania numana*)), *Drypetes deplanchei* (for White Albatross (*Appias albina albina*)), *Excoecaria ovalis* (for Mangrove Jezebel (*Delias aestiva aestiva*)), *Millettia pinnata* (for Chrome

Awl (*Hasora chromus*)), and *Strychnos lucida* (for Princess Flash (*Deudorix smilis*)). Similarly, the following shrubs are the only native food plants for three species of butterflies/diurnal moths in the Darwin region: *Boronia lanceolata* (for Spotted Opal (*Candalides urumelia*), at Channel Island), *Flacourtia territorialis* (for Spotted Rustic (*Phalanta phalantha*)), and *Leea rubra* (for Painted Day-moth (*Agarista agricola biformis*)).

Vines are particularly important for a number of butterflies, and at least eight species specialise on single species of vines, as follows: *Adenia heterophylla* (by Orange Lacewing (*Cethosia penthesilea*)), *Cassytha filiformis* (by Small Dusky-blue (*Erina erina*)), *Derris trifoliata* (by Broad-banded Awl (*Hasora hurama*)), *Embelia curvinervia* (by White-banded Line-blue (*Nacaduba kurava felsina*)), *Flagellaria indica* (by Bright-orange Darter (*Telicota augias*)), *Galactia tenuiflora* (by Scalloped Grass-yellow (*Eurema alitha*)), *Marsdenia geminata* (by Two-brand Crow (*Euploea sylvester pelor*)), and *Trophis scandens* (by Small Brown Crow (*Euploea darchia darchia*)). Several herbs, grasses and sedges are also important, with 10 species serving as the only natural food plants in the Darwin region: *Aristolochia holtzei* (for Clearwing Swallowtail (*Cressida cressida*)), *Chamaecrista mimosoides* (for Macleay's Grass-yellow (*Eurema herla*)), *Patersonia macrantha* (for Northern Iris-skipper (*Mesodina gracillima*)), *Portulacca oleracea* (for Danaid Eggfly (*Hypolimnas misippus*)), *Pseuderanthemum variabile* (for Blue-banded Eggfly (*Hypolimnas alimena darwinensis*)), *Typhonium flagelliforme* (for Tiger Day-moth (*Cruria darwiniensis*)), *Triodia bitextura* (for Spinifex Sand-skipper (*Proeidosa polysema*)), *Chrysopogon latifolius* (for Northern White-spotted Sun-moth (*Synemon phaeoptila*)), *Cyperus javanicus* (for Riverine Sedge-skipper (*Hesperilla sexguttata*)), and *Scleria sphacelata* (for Wide-brand Sedge-skipper (*Hesperilla crypsigramma*)). This conservatism in food plant preference highlights the extreme specialisation of Lepidoptera and their host plants – butterflies and diurnal moths are fussy eaters!

In addition to providing the appropriate species of plant for particular species of butterflies/diurnal moths, several members of the Lycaenidae also require ants. For Shining Oak-blue (*Arhopala micale*), Purple Oak-blue (*A. eupolis asopus*), Black-spotted Flash (*Hypolycaena phorbas*) and Dark Ciliate-blue (*Anthene seltuttus*), the larvae are reliant on the Green Tree Ant (*Oecophylla smaragdina*). Because this ant is a common arboreal species in savannah woodland and along the edges of monsoon forest/vine thicket, generally little provision needs to be made to establish colonies of the ant. The ant is also the food for the Moth Butterfly (*Liphyra brassolis*), which does not feed on plants but consumes the ant brood inside the ant-nest (i.e. myrmecophagous). However, the larvae of other species that have specific obligate associations with ants will not survive unless colonies of the appropriate ant species are present. For example, Northern Purple Azure (*Ogyris zosine*) and Fiery Jewel (*Hypochrysops ignitus*) require subterranean colonies of *Camponotus* sp. and *Papyrius* sp., respectively, whereas Copper Jewel (*Hypochrysops apelles*) requires *Crematogaster* sp., which live in the mature trees of its mangrove food plants, especially *Lumnitzera racemosa*. Orange-tipped Azure or Dodd's Azure (*Ogyris iphis doddi*), should it still occur in the Darwin region, requires extensive colonies of the ant *Froggattella kirbii* in addition to its mistletoe food plant.

It is envisaged that the list of food plants provided herein will encourage suburban residents and those living in the rural area, as well as non-government organisations (e.g. Top End Native Plant Society, Greening Australia) and the Darwin City Council, to propagate and establish indigenous species to attract butterflies and diurnal moths to their suburban gardens, parklands and roadside verges (i.e. green spaces). Insects play important roles in ecosystem function, such as pollination, nutrient cycling, herbivory and provide food for other animals, such as vertebrates (e.g. reptiles and birds) (Taylor *et al.* 2018). The larvae of butterflies and moths rarely kill their food plants by overexploitation, although in some circumstances they may cause temporary defoliation when numbers are high. However, in our experience the plants quickly recover from such instances of herbivory.

In addition to the above-mentioned biodiversity and environmental benefits of growing indigenous plants, such species have the advantage of being more likely to successfully establish as they are inherently adapted to local climatic and soil conditions. Some local indigenous plants are available commercially through various nursery outlets. However, many species have not been developed horticulturally due to their actual or perceived lack of ornamental appeal (e.g. absence of large showy flowers). Relatively few of the larval food plants listed in this article are readily available in retail nurseries, but many may be amenable to cultivation, after propagation from seed or stem cuttings, or by transplanting or division of plants (Appendix 1). Cultivation of others remains uncertain or has not been tried. Information on propagation and cultivation of local native plants is available from plant nurseries, Top End Native Plant Society or online, for example, via Greening Australia and Gardening Australia websites.

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Appendix 1. Annotated list of larval food plants for butterflies and diurnal moths occurring in the Darwin region. Plant species are listed alphabetically according to life form. For habitat: Sw = savannah woodland, Mv = monsoon vine forest or semi-deciduous monsoon vine thicket, P = paperbark woodland/swampland (freshwater), Ma = mangrove or saltmarsh (saltwater). For cultivation: S = from seed, C = from cutting, D = from transplant or division. ? = uncertain/untried. For plant part eaten: L = leaf, Ly = leaf (young new growth only), Fb = flower bud, Fl = flower, S = seed, W = stem woody, V = vine photosynthetic, R = root. Note that the mistletoes *Amyema*, *Decaisnina signata* and *Dendrophthoe* also require a host tree to survive.

Plant species	Habitat	Amenable to cultivation	Butterfly/ diurnal moth species	Plant part eaten
Palm				
Carpentaria acuminata	Mv	S	*Cephrenes augiades*	L
Livistona benthamii	P	S	*Cephrenes trichopepla*	L
Livistona humilis	Sw	S	*Cephrenes trichopepla*	L
Tree				
Acacia auriculiformis	Mv	S	*Prosotas dubiosa*, *Theclinesthes miskini*	Fb/Fl, L
Alphitonia excelsa (sapling)	Sw	S	*Hypochrysops ignitus*	L
Atalaya variifolia (sapling)	Sw	S?	*Theclinesthes miskini*	L
Buchanania obovata	Sw	S	*Arhopala eupolis*	Ly
Calophyllum inophyllum	Mv	S	*Arhopala micale*	Ly
Carallia brachiata	Mv	S	*Dysphania numana*	L
Ceriops australis	Ma		*Hypochrysops apelles*	L
Corymbia bella	P	S	*Arhopala eupolis*	Ly

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Plant species	**Habitat**	**Amenable to cultivation**	**Butterfly/ diurnal moth species**	**Plant part eaten**
Corymbia bella (sapling)	P	S	*Theclinesthes miskini*	L
Corymbia disjuncta	Sw	S	*Anthene seltuttus, Arhopala eupolis*	Ly, Ly
Corymbia ferruginea (sapling)	Sw	S	*Theclinesthes miskini*	L
Cryptocarya cunninghamii	Mv	S	*Graphium eurypylus*	Ly
Cupaniopsis anacardioides	Mv	S	*Prosotas dubiosa, Anthene lycaenoides, Anthene seltuttus, Arhopala eupolis, Arhopala micale*	Fb, Fb/Fl/Ly, Ly, Ly, Ly
Drypetes deplanchei	Mv	S	*Appias albina, A. paulina*	Ly, Ly
Excoecaria ovalis	Ma		*Delias aestiva*	L
Ficus virens	Mv	S	*Euploea corinna*	Ly
Gardenia megasperma (sapling)	Sw	S	*Hypochrysops ignitus*	L
Huberantha nitidissima	Mv	S	*Graphium eurypylus*	Ly
Lumnitzera racemosa	Ma		*Hypochrysops apelles*	L
Mallotus nesophilus	Mv	S	*Catopyrops florinda*	Fb/Fl/Ly
Maranthes corymbosa	Mv	S, C	*Arhopala eupolis*	Ly
Maranthes corymbosa (sapling)	Sw	S, C	*Hypochrysops ignitus*	L
Miliusa traceyi/brahei	Mv	S	*Graphium eurypylus*	Ly
Millettia pinnata	Mv	S	*Anthene lycaenoides, A. seltuttus, Hasora chromus, Jamides phaseli, Prosotas dubiosa*	Fb/Fl/Ly, Ly, Ly, Fb/Fl/Ly, Fb/Fl

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Plant species	Habitat	Amenable to cultivation	Butterfly/ diurnal moth species	Plant part eaten
Planchonia careya	Sw	S	*Chaetocneme denitza*, *Hypolycaena phorbas*	L, L
Planchonia careya (sapling)	Sw	S	*Hypochrysops ignitus*	L
Sterculia quadrifida	Mv	S	*Arhopala micale*	Ly
Strychnos lucida	Mv		*Deudorix smilis*	Ft
Terminalia ferdinandiana	Sw	S	*Arhopala eupolis*	Ly
Terminalia microcarpa	Mv	S	*Badamia exclamationis*	Ly
Zanthoxylum rhetsa	Mv	S	*Papilio fuscus*	L
Vitex acuminata	Mv	S, C	*Charaxes sempronius*	L
Tree/shrub				
Barringtonia acutangula	P	S	*Anthene lycaenoides*	Fb/Fl/Ly
Capparis umbonata	Sw	S	*Belenois java, Cepora perimale*	L, L
Clerodendrum floribundum	Mv, Sw	S	*Hypochrysops ignitus, Hypolycaena phorbas*	L, L
Ficus aculeata	Sw	S, C	*Euploea corinna*	Ly
Glochidion apodogynum (sapling)	Sw	S	*Hypochrysops ignitus*	L
Shrub				
Acacia difficilis	Sw	S	*Theclinesthes miskini*	L
Acacia holosericea	Sw	S	*Theclinesthes miskini*	L
Ampelocissus frutescens	Sw, Mv	S?	*Periopta ardescens*, *Radinocera vagata*, *Pseudosesia oberthuri*	Ly, Ly, W
Boronia lanceolata	Sw	S, C	*Candalides urumelia*	L

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Plant species	**Habitat**	**Amenable to cultivation**	**Butterfly/ diurnal moth species**	**Plant part eaten**
Bossiaea bossiaeoides	Sw	S	*Jamides phaseli*	L
Brachychiton megaphyllus	Sw	S	*Hypochrysops ignitus*	L
Breynia cernua	Sw, Mv	S, C	*Eurema hecabe, Hypolycaena phorbas*	Ly, L
Bridelia tomentosa	Sw, Mv		*Anthene lycaenoides*	Fb/Fl/Ly
Cathormion umbellatum	P	S	*Theclinesthes miskini*	L
Chamaecrista mimosoides	Sw		*Eurema herla*	L
Crotalaria novae-hollandiae	Sw	S	*Lampides boeticus*	Fb/Fl/S
Cullen badocanum	Sw	S	*Papilio demoleus*	L
Dodonaea hispidula	Sw	S	*Catopyrops florinda*	Fb/Fl/Ly
Flacourtia territorialis	Mv	S?	*Phalanta phalantha*	Ly
Flemingia lineata	Sw	S	*Catochrysops panormus, Freyeria putli*	Fb/Fl/Ly, Fl/L
Glycosmis trifoliata	Mv	S	*Papilio fuscus*	L
Hibbertia brevipedunculata/cistifolia	Sw	C	*Idalima aethrias*	L
Hibbertia dilatata/juncea	Sw	C	*Idalima metasticta*	L/Fl
Leea rubra	Mv	S, C	*Agarista agricola*	Ly
Micromelum minutum	Mv	S	*Papilio fuscus*	L
Senna surattensis	Sw, Mv	S	*Anthene lycaenoides, Catopsilia scylla*	L, L
Sesbania cannabina	P	S, C	*Eurema hecabe, Theclinesthes miskini*	L, L

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Plant species	Habitat	Amenable to cultivation	Butterfly/ diurnal moth species	Plant part eaten
Vine/shrub				
Capparis sepiaria	Mv	S	*Appias paulina, Belenois java, Cepora perimale, Elodina walkeri*	Ly, L, L, L
Cyß∑nanchum viminale	Sw	C	*Euploea corinna*	Ly
Embelia curvinervia	Mv		*Nacaduba kurava*	Fl/Ly
Vine				
Adenia heterophylla	Mv	C?	*Acraea andromacha, Cethosia penthesilea*	L
Ampelocissus acetosa	Sw, Mv	S?	*Periopta ardescens, Radinocera vagata, Pseudosesia oberthuri*	Ly, Ly, W
Canavalia rosea	P	S	*Jamides phaseli*	Fb/Fl
Cassytha filiformis	Sw, Mv, P		*Erina erina*	V
Cayratia maritima	P	C?	*Radinocera vagata*	Ly
Cayratia trifolia	Sw	C	*Cruria donowani, Radinocera vagata*	Ly, Ly
Cynanchum carnosum	P	C?	*Danaus affinis, D. petilia, Tirumala hamata*	Ly, Ly, Ly
Cynanchum pedunculatum	Sw	C?	*Danaus petilia*	Ly
Derris trifoliata	Ma		*Hasora hurama*	Ly
Flagellaria indica	Mv		*Anthene lycaenoides, Telicota augias*	Fb/Fl/ Ly, L
Gymnanthera oblonga	Ma, P		*Euploea corinna*	Ly
Ichnocarpus frutescens	Mv	C?	*Euploea corinna*	Ly

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Plant species	**Habitat**	**Amenable to cultivation**	**Butterfly/ diurnal moth species**	**Plant part eaten**
Marsdenia geminata	Mv	S?	*Euploea corinna, E. sylvester*	Ly, Ly
Marsdenia glandulifera	Mv	S?	*Tirumala hamata*	Ly
Marsdenia velutina	Mv	S?	*Tirumala hamata*	Ly
Marsdenia viridiflora	Sw	S?	*Danaus affinis, Euploea corinna*	Ly, Ly
Secamone elliptica	Mv	C?	*Euploea corinna, Tirumala hamata*	Ly, Ly
Smilax australis	Mv, Sw		*Hypochrysops ignitus, Hypolycaena phorbas*	L ,L
Thunbergia arnhemica	Mv, Sw		*Junonia orithya*	L
Trophis scandens	Mv	S	*Euploea darchia*	Ly
Tylophora flexuosa	Mv	S?	*Danaus petilia*	Ly
Vigna (4 species)	Sw	S	*Euchrysops cnejus, Famegana nisa*	Fb/Fl/S, Fb/Fl
Vine/herb				
Galactia tenuiflora	Sw, Mv	S	*Eurema alitha*	L
Herb				
Aristolochia holtzei	Sw		*Cressida cressida*	L
Buchnera (3 species)	Sw		*Junonia orithya*	L/Fl
Hybanthus enneaspermus	Sw		*Acraea andromacha, A. terpsicore*	L, L
Hygrophila angustifolia	P		*Junonia hedonia*	L
Indigofera linifolia	Sw		*Freyeria putli*	Fl/L
Patersonia macrantha	Sw	D	*Mesodina gracillima*	L

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Plant species	**Habitat**	**Amenable to cultivation**	**Butterfly/ diurnal moth species**	**Plant part eaten**
Phyllanthus sp.	Sw		*Eurema hecabe*	L
Portulacca oleracea	Sw		*Hypolimnas misippus*	L
Pseuderanthemum variabile	Mv, Sw	C/D?	*Hypolimnas alimena, Junonia orithya*	L, L
Spermacoce phalloides	Sw		*Periopta diversa*	L
Tecticornia (3 species)	Ma		*Theclinesthes sulpitius*	L
Typhonium flagelliforme	P		*Cruria darwiniensis*	Ly
Tribulus cistoides	Sw		*Zizeeria karsandra*	L
Grass				
Aristida macroclada	Mv, Sw	D	*Hypocysta adiante*	L
Arundinella nepalensis	P	D	*Hypocysta adiante*	L
Chrysopogon latifolius	Sw	D	*Synemon phaeoptila*	R
Cymbopogon procerus	Sw	D	*Taractrocera ina*	L
Digitaria gibbosa	Sw		*Hypocysta adiante*	L
Eulalia aurea	Sw	D	*Taractrocera anisomorpha*	L
Hymenachne acutigluma	P		*Borbo impar*	L
Imperata cylindrica	P, Sw	D	*Melanitis leda, Mydosama sirius, Suniana lascivia, Telicota colon*	L, L, L, L
Ischaemum australe	P	D	*Hypocysta adiante, Melanitis leda, Suniana lascivia, Telicota colon*	L, L, L, L

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Plant species	Habitat	Amenable to cultivation	Butterfly/ diurnal moth species	Plant part eaten
Mnesithea rottboellioides	Sw	D	*Pelopidas lyelli, Telicota colon*	L, L
Sorghum intrans	Sw	D	*Neohesperilla xiphiphora*	L
Triodia bitextura	Sw	D	*Proeidosa polysema*	L
Sedge				
Cyperus javanicus	P	D	*Hesperilla sexguttata*	L
Scleria sphacelata	Sw, Mv	D	*Hesperilla crypsigramma*	L
Mistletoe				
Amyema benthamii	Sw		*Ogyris amaryllis, O. zosine*	L, L
Amyema bifurcata	Sw		*Comocrus behri, Ogyris amaryllis, O. oroetes, O. zosine*	L, L, L, L
Amyema miquelii	Sw		*Delias argenthona, Eirmocides margarita, Ogyris amaryllis, O. zosine*	L, Fb/Fl/Ly, L, L
Amyema sanguinea	Sw		*Birthana cleis, Comocrus behri, Delias argenthona, Eirmocides margarita, Ogyris amaryllis, O. iphis, O. zosine*	L, L, L, Fb/Fl/Ly, L, L, L
Amyema thalassia	Ma		*Ogyris amaryllis*	L
Amyema villiflora	Mv, Sw		*Comocrus behri, Eirmocides margarita, Ogyris zosine*	L, Fb/Fl/Ly, L
Decaisnina signata	Sw, Mv		*Birthana cleis, Delias argenthona, Eirmocides margarita, Hypolycaena phorbas, Ogyris zosine*	L, L, Fb/Fl/Ly, L, L
Dendrophthoe glabrescens/ odontocalyx	Sw		*Birthana cleis, Delias argenthona, Eirmocides margarita*	L, L, Fb/Fl/Ly

Gastropod-like caterpillar cases on Turkey Bush

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Abstract

Illustrations of three stages (larva, pupa, adult) of the life cycle of the xyloryctid moth *Plectophila* sp. are provided. The larva constructs a helical case solely on Turkey Bush (*Calytrix exstipulata*) in the Top End of the Northern Territory. The full life cycle and other aspects of the biology of this species are unknown.

There is a species of moth in the Top End of the Northern Territory whose larva (Figure 1) constructs a spirally coiled case (Figure 2) solely on Turkey Bush (*Calytrix exstipulata*) (photograph of flowers on front cover of this issue of *Northern Territory Naturalist*). The case is made from silk and decorated with leaves and other small pieces of material from the food plant. The case, which resembles a small gastropod shell, consists of up to three loose spiral coils with adjacent coils not quite touching each other. The direction of coiling is usually, but not always, sinistral (left-coiled). Figure 2 illustrates a dextral (right-coiled) case. The opening of the case has a long flap (Figure 3) on the outer part of the entrance that the larva can hold closed with a few strands of silk especially when it is inactive. The larva itself is white with reddish marks and the head and pronotal shield are also mottled, but darker (Figure 1).

The life cycle and ecology are otherwise unknown. The eggs are probably laid in the tips of younger *Calytrix exstipulata* foliage, although the larvae can be quite mobile (based on observations of captive specimens). The cases are mostly found on the outer branches where fresher leaves are present but not on the lower branches which are often dead. A larva remains in the same case, expanding it by adding to the opening as it grows. A living pupa has not been observed as yet, but it is presumed to also occur in the larval case which remains attached to the plant even after the moth has emerged (Figure 4).

There are 10 described species of *Plectophila* in Australia. The genus is hitherto unrecorded from the Northern Territory (Edwards, 2008). The Top End species (Figures 5–6) is apparently undescribed, but is closely related to *Plectophila thrasycosma* and *P. electella* based on the almost identical colour patterns on the wings. The former species ranges from the drier parts of the Atherton Tableland, south to the Lockyer Valley of Queensland, whereas the latter ranges from Moreton Bay in Queensland, to South Australia (Edwards, 2008). *Plectophila thrasycosma* was originally described from reared larvae living in individual coiled, gastropod-like cases. These larvae were feeding on the leaves of Narrow-leaved Ironbark (*Eucalyptus crebra*) near Townsville and the cases were covered

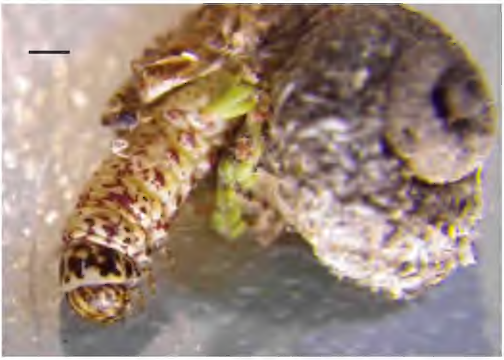

Figure 1. Freshly dead larva of *Plectophila* sp. partially removed from its case. The larva had added fresh leaves of *Calytrix exstipulata* to the opening of the case immediately prior to being collected. Scale 1 mm (Graham Brown)

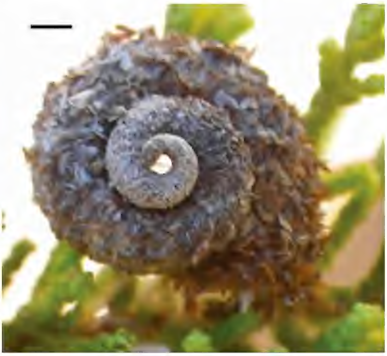

Figure 2. Detail of larval case *in situ* from above. Note that this is a dextral (right-coiled) case. Scale 1 mm (Graham Brown)

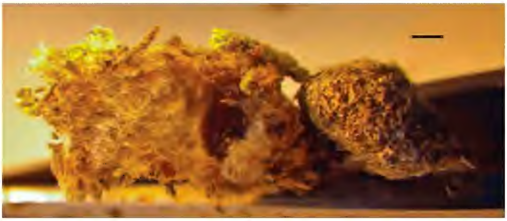

Figure 3. Detail of exposed case flap (on left), opening of case with larval head just visible (centre), and case itself (on right). Scale 1 mm (Graham Brown)

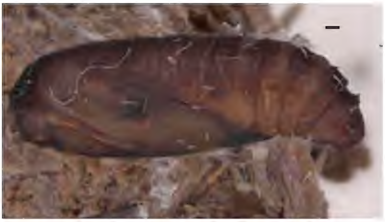

Figure 4. Pupa dissected out of its case. Scale 0.5 mm (Graham Brown)

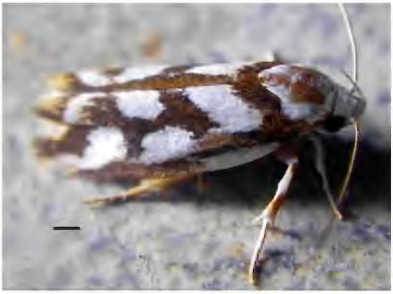

Figure 5. Live adult *Plectophila* sp. Scale 1 mm (Graham Brown)

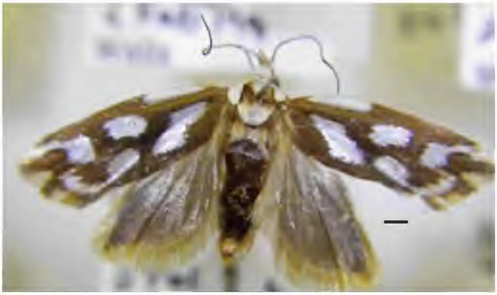

Figure 6. Pinned preserved adult *Plectophila* sp. Scale 1 mm (Graham Brown)

in faecal pellets. Differences in host plant preference, leaf size and the material used to decorate the larval cases also suggest this Top End taxon is a new, closely related species. Or this could be the result of the size of the leaves of the regionally chosen host plants; the leaves are 2 mm in length in *C. exstipulata* and loosely attached to the case compared to 50–180 mm long in *E. crebra* and would thus need to be cut into small pieces.

The known distribution of this Top End *Plectophila* sp. is from the Darwin region to the vicinity of Mary River National Park but it is patchy both temporally and geographically, and the larval cases can be hard to find because they blend in with the colour of the stems and detritus. It is usually rare in Darwin although Richard Willan found a small population on 2–3 plants on the northern boundary of the Casuarina Campus of Charles Darwin University, Darwin, where it persisted for about four years. There is also a long series of reared moths from Casuarina Coastal Reserve, Darwin (including the pupal photograph reproduced here), in the Entomology Collection in the Museum and Art Gallery of the Northern Territory.

The biology of the described Australian species of *Plectophila* is unknown.

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Observations on relocation of a nest by a colony of Red Honey Ants (*Melophorus bagoti*)

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Abstract

The desert-dwelling Australian Red Honey Ant (*Melophorus bagoti*) rarely moves from one nest site to another. We observed the relocation of one colony of this ant at a field site about 10 km south of Alice Springs. This relocation, which was 36 m from the old nest, took 17 days to complete with the relocation of the brood itself taking only 1 to 2 days. During this unexpected move, we observed a large amount of outdoor activity by guard ants and physical contact between guard ants, as well as between guard ants and foragers. This amount of contact between the guard ants and foragers has never been described before. The relocation apparently resulted from experimental changes around the nest site above ground, a conclusion that differs from that of the only other study on this species which suggested that interference with the actual nest underground triggered the relocation.

Introduction

Nest relocation in ants is an activity wherein all the members living within a nest colony co-ordinate their activities to move from one location to another in a collective manner. Various factors trigger nest relocation in different species of ants. Colonies of the Argentine Ant (*Linepithema humile*) are seasonally polydomous, and changes in humidity drive nest movement (Heller & Gordon 2006). Flooding is another major reason for nest relocation (Scholes & Suarez 2009). In the case of a severe flood, *L. humile* relocates faster than during a typical move. During a flood, this species also chooses a safe location more often than does the Odorous House Ant (*Tapinoma sessile*) of North America, which often splits its colonies into two when flooding is high. A *T. sessile* colony splits because some workers move rapidly to a new location while others remain in the nest and move deeper into the lower chambers by preference (Scholes & Suarez 2009). External and internal factors influence emigrations in the surface-adapted bivouac-forming species of doryline ants of the genus *Aenictus* (i.e. *A. laeviceps* and *A. gracilis).* Usually within 20 minutes after the first signs of excitement, emigration starts in the bivouac. The external factor stimulating the emigration activity is the raiding on an *Aenictus* colony by *Eciton* ants, whereas internally, food-depleted larvae initiate the intra-bivouac excitation of the colony (Schneirla & Reyes 1969). Funnel Ants (*Aphaenogaster barbigula*) make their nests in aeolian soils that are usually dry and prone to erosion. These ants change the location of their nests twice a year on average. During the construction of nest entrances in a new location, workers repack the soil, a process called bioturbation (Eldridge & Pickard 1994). Only two observations of nest relocation have been made on desert-living ants to date – on the Spanish *Cataglyphis iberica* (Dahbi *et al.* 2008) and on the Australian Red Honey Ant (*Melophorus bagoti*) (Schultheiss *et al.* 2010).

The endemic Australian *Melophorus bagoti* is a thermophilic ant, occupying an equivalent ecological niche to the African/Saharan genus *Cataglyphis* and the Namibian genus *Ocymyrmex* (Wehner 1987; Conway 1992). *Melophorus bagoti* colonies are widespread in the Central Australian desert, with the ants making their nests in sandy soil. The vegetation around the nest area is dominated by low shrubs and Spinifex and Buffel Grass tussocks. One single colony of *M. bagoti* contains approximately 2800 ants consisting of workers, queens, males and repletes (Conway 1992). *Melophorus bagoti* colonies exhibit polymorphism; the ants having large differences in their body size (Conway 1992). The repletes are also known as 'honey pots' because their gaster is distended as they store liquid food in their abdomen, hence the species is commonly called the Red Honey Ant. Their most common nickname throughout the course of history was Ituny Ituny (which means sun sun); yet now they are also referred to as Furnace Ants since they forage in the hottest time on summer days (Cheng *et al.* 2014). Furthermore, there is often a clear division of responsibilities between different morphs of workers. Large workers, guard ants or soldiers, often guard their nest by patrolling the entrance, whereas the other younger workers (which are smaller in size) run outside to forage during the hottest time of the day (Conway 1992). *Melophorus bagoti* shares the surrounding physical habitat with other arthropods, but specialises in its temporal niche. Whilst workers search for food individually during the hottest part of summer days, they stop foraging in winter. Outbound and homebound activities depend largely on the soil surface temperature (Conway 1992). During natural foraging in the summer months, when the soil surface temperature reaches about 50°C, these ants become active and continue to forage up to 70°C (Christian & Morton 1992; Conway 1992; Muser *et al.* 2005; Schultheiss & Nooten 2013). They forage solitarily during the hot summer day, running on their long legs for food. They mostly scavenge dead insects but also collect seeds, sugary plant exudates and other miscellaneous items (Muser *et al.* 2005).

As mentioned above, one study has previously reported on the relocation of a *Melophorus bagoti* colony (Schultheiss *et al.* 2010). The authors concluded that *M. bagoti* nest moves were uncommon and the ants did not change the location of their nest for many years. However, the colony frequently relocated the entrance to the nest by 5 to 191 cm (average 73 cm) due to unknown reasons. When Schultheiss and his team accidentally opened one of the old entrances while cleaning up the area surrounding a nest for experimentation, they found that after eight days the whole colony relocated 17.75 m away from the old entrance to the nest (Schultheiss *et al.* 2010). These researchers assumed that the relocation of the nest was likely due to nest disturbances (Schultheiss *et al.* 2010).

When planning and performing experiments on the focal nest of *M. bagoti*, we witnessed the nest relocation of a colony. This process included ants searching for new sites, preparing a new nest, and finally moving the entire colony into the new home.

Materials and Methods

The study was conducted at a field site located about 10 km south of Alice Springs. The red soil at the study site was composed of sand sediments laid down by floods. The desert habitat's vegetation is dominated by Buffel Grass (*Pennisetum cenchroides*) plus a mosaic of *Acacia* bushes and *Eucalyptus* trees. We observed one particular colony's activities from 9–28 January 2018. Navigation and orientation in *M. bagoti*, as with other ant species, is primarily dependent on vision derived from terrestrial and celestial cues (Cheng *et al.* 2009; Wystrach *et al.* 2011; Freas *et al.* 2017; Deeti *et al.* 2020). In a proposed study related to the learning walks of naive *M. bagoti* individuals belonging to this colony, we removed the vegetation around the focal nest on 9 January. All the ants appearing outside the nest were marked with a dot of black paint on their gaster. Over a period of five days, 550–600 foragers were painted with the same colour. We then classified them as seasoned foragers and considered all the unpainted ants to be naive ants after this period. In the morning of the sixth day, we plotted a 1 m^2 grid around the nest (Figure 1C). Each naive ant was marked with a distinctively coloured dot of paint on its body on the sixth and seventh days to observe its learning walks. The nest became

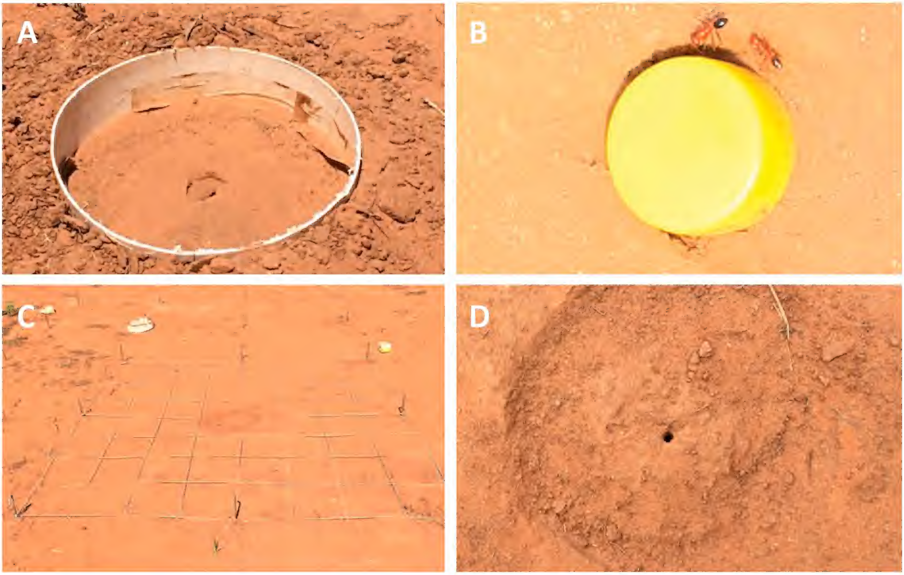

Figure 1. Overview of experimental disturbances around the nest. **A.** A plastic ring barrier covered with a sand ramp, **B.** a plastic cap on the nest to block the outbound and homebound runs, **C.** synthetic string forming a grid of 1m squares around the nest and **D.** removal of the plastic ring barrier from the nest surroundings to observe the learning walks.

inactive on the next two (i.e. eighth and ninth) days. On the tenth day, the ants opened a new entrance in the afternoon when the colony was less active and no foraging activity was being undertaken. They changed the entrance again on the eleventh day, a day on which we had painted the emerging unpainted ants (about 40) with a black dot. The relocation of the nest colony was observed to start on the sixteenth day (i.e. 24 January). All the ants coming out of the nest were documented by counting them during the relocation. We also occasionally videorecorded the traffic of the ants from the old nest.

Results

Observations at the old nest site

The first observation was that after seven days of preparation to observe initial learning walks, the colony became inactive for two days (Table 1). During days eight and nine, only a single guard ant emerged at 11.30 hr on day eight, searched extensively by making a few forays around the nest, and then returned to the nest. The second observation was made on the afternoon of the tenth day: a new entrance (1st entrance) was opened by some of the workers 81 cm west from the old entrance. From midday that day until the colony closed the nest, about 10–15 painted worker ants went off foraging for short periods. No ants came out of the new entrance on the morning of the next (eleventh) day, and the colony opened another entrance (i.e. the second entrance) on the north-east side 114 cm from the original nest entrance. They closed the second entrance after an hour and became active through another entrance (i.e. the third entrance), opening 180 cm north-east of the old entrance to the colony. This third entrance remained active until the relocation of the colony.

On the eleventh day, around 11.00 hr, we observed a large number (about 40) of guard ants moving outside of the nest over a 30 minute period, and they were performing longer runs than normal. Usually only 5–10 guard ants performed outbound runs per day. Physical contacts were also observed during the same day between guard ants and foragers (Figure 2).

Table 1. Characteristics of emigration from *M. bagoti* nest.

Date and day number	Immigration activity
16/1/2018 to 18/1/2018 (days 8 to 9)	Inactive colony, only one outside guard ant activity was observed.
18/1/2018 to 19/1/2018 (days 9 to 11)	New entrances were found at the old nest at 81 cm and 114 cm from the original nest entrance.
20/1/2018 (day 12)	Continuous outward behaviour was observed in 30 to 40 guard ants.
20/1/2018 to 23/1/2018 (days 13 to 15)	Workers and guard ants found digging the new nest 36 m from the old nest.
24/1/2018 (day 16)	Emigration to the new site was observed and continued throughout the day.
25/1/2018 to 26/1/2018 (days 17 to 18)	Less immigration from the old nest and more functions of colony building were observed at the new site.
26/1/2018 to 28/1/2018 (days 18 to 20)	During this time, changes in the entrance were noticed twice.

Activities at the relocation site

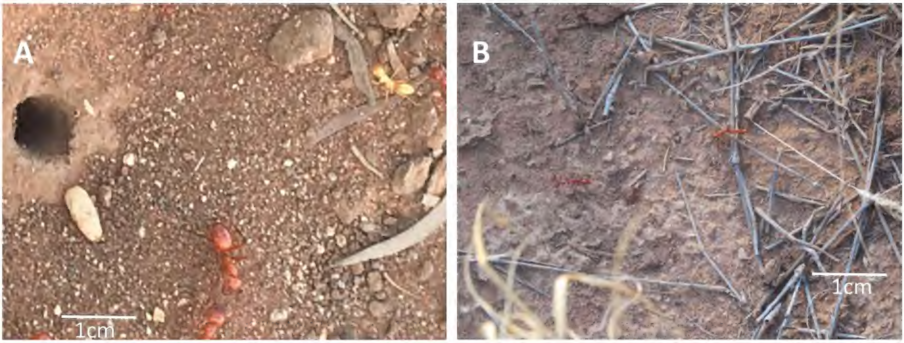

Figure 2. A. *Melophorus bagoti* workers, replete with the inflated abdomen that varies in colour from amber to milky white, callow (yellow to orange colour), and larvae at the old nest entrance. **B.** Physical contact between ants during the relocation. In the above image, guard ants and foragers are found contacting each other with their antennae.

On the twelfth day, at 36 m north from the old nest, a few guard ants, foragers and painted naive ants were observed digging a new nest. The excavation activity continued throughout the day (between 09.00 hr and 18.00 hr) for four days. We noticed similar nest digging activity on the sixteenth day at 09.00 hr and we also observed moves on the same day at 09.30 hr. During the relocation process, we observed the complete cessation of foraging out of the old nest.

On the morning of the sixteenth day, the colony started relocating its nest. From our earlier observations, we had found that normally only 4-5 naive ants appeared daily; however, 15–20 naive ants were noticed/painted on the morning of 24 January between 09.00 hr and 09.30 hr. Suddenly, at 09.30 hr, a huge number of unpainted ants, painted foragers and guard ants started to appear. About 20 of the ants started moving towards the relocation site and the remaining foragers/workers and guard ants milled around the entrance. At the same time, unpainted ants came out of the nest. Some of them carried larvae in their mandibles, then left them outside the nest and returned inside again. Workers and unpainted ants (novices) continuously pulled the callows (identified by colour), eggs and larvae out to the entrance. Guard ants and experienced foragers that were moving around the nest were picking up the larvae and steadily moving them towards the new nest (Figure 2). A few unpainted ants were trying to get into the older nest with the help of foragers. Many repletes were also noticed and they were much larger, orange in colour, and most of their abdomens were filled. As previously described by Conway (1992), we discerned two forms of repletes – those with dark amber-coloured abdomens and those with milky white abdomens.

The relocation of the nest proceeded throughout the day with the highest rate in the morning and afternoon, dipping during the middle of the day, and stopping before sunset. The majority of the workers, guard ants, repletes, callows, larvae and eggs had

Table 2. Estimated numbers of different worker castes of *M. bagoti* transported to the relocation site during the emigration.

Transport Date	Workers	Guard ants	Repletes	Callows	Larvae/ pupae/ eggs
21/1/2018	25-30	5-10			
24/1/2018	1400	120	90	40	118
25/1/2018	50	5			10

shifted themselves (or were transported to) the relocation site by 24 January (i.e. the sixteenth day) (Table 2). During the move, including even at mid-day, most of the experienced foragers and the guard ants moved back and forth between the old and the new nest to transport the brood and callows. The moves peaked from 09.30 hr to 10.30 hr and from 16.30 hr to 18.00 hr, with a maximal activity on the sixteenth day and minimal activity for the next two days. On the seventeenth day they did not open the nest entrance until 11.30 hr at the relocation site and that new entrance was 84 cm west of the new nest. At that time, about 30–40 workers and guard ants from the old nest were noticed waiting outside for the new nest's entrance to be opened. When the nest entrance was opened, 30–40 ants went inside, and during the day only 10 larvae were transported to the new nest. In that time no repletes or callows were observed. Some foragers and guard ants were seen walking into the old nest from the new nest and vice versa without carrying anything. Queens and males were not observed at all during this time, and it remains unclear whether they had remained in the old nest or had moved to the new site unobserved. The transport of the ants to the new site finished on the seventeenth day (i.e. 25 January), so that transportation of the brood was completed in 1 to 2 days.

From 26 January (i.e. the eighteenth day) to 6 March, the activity at the new nest and its changes were inspected for one hour (8.30–9.30 hr) before the nest activity started for the day and for one hour (17.00–18.00 hr) after the activity had ended. During this period, the entrance was changed twice – firstly 87 cm away from the original entrance and secondly 10 cm away from the original entrance. The activity at the old nest, however, was sporadic after relocation, and occasionally a few ants took back-and-forth round trips between it and the new nest. During the subsequent study season, no activity was observed at the old nest site whatsoever.

Discussion

In summary, we had the good fortune to observe by chance the relocation of a nest by a colony of *Melophorus bagoti*. The ants excavated a new nest and moved all workers and the brood into the new nest. The ants accomplished all the brood transportation in just 1 to 2 days (Figure 2).

Many ant species explore for a while before moving their nest (Abraham & Pasteels 1980; Mallon *et al.* 2001). Soil-nesting ants have to build a nest before or during a move, which takes up to a week in *Atta colombica and Pogonomyrmex badius*. The ground-nesting desert ant *Cataglyphis iberica* does not need to explore or prepare nests as it is polydomous and has several nests ready to inhabit. Their multi-nest system shortens the time for migration and decreases the risks faced by the colonies. Our *Melophorus bagoti* colony took four days to dig its new nest, probably because the population was large.

During the unexpected move of the *M. bagoti* colony, we observed a large amount of outdoor activity by guard ants and physical contact between guard ants as well as between foragers and guard ants. This amount of contact between the guard ants and foragers has never been described before. After this instance, the guard ants, along with foragers, were noticed at the new nest. We do not know whether, during their first discovery, the ants somehow marked the new nest site, and this possibility should be explored.

Schultheiss *et al.* (2010) suggested that the nest move that they observed in this species was triggered by accidental structural damage to one of the chambers underground. But it remains unclear why the nest they studied and the nest we studied moved in response to experimental disturbance, whereas many other nests over many years of experimentation at this field site did not do so. Since the study reported here, we have studied other colonies of the same species in the same season, painting numerous individuals and setting up grids, but no relocation has taken place in any of these other colonies.

Some species of ant spread their colony throughout the nesting season to several nests and contract to one or more nests during the dormant season (Heller & Gordon 2006; Buczkowski & Bennett 2008; Laskis & Tschinkel 2009). Nest emigration seems to be typical in forest-dwelling ant species (Smallwood 1982). However, it seems to be rare in the desert-dwelling *M. bagoti*, wherein generally a nest does not relocate over many years. Nonetheless, behavioural and ecological field studies are still sparse and more research is needed to understand the causes of nest relocation of these ants.

Acknowledgements

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Northern Territory Naturalist (2021) 30: 108-137 Research Article

A conspectus of the freshwater molluscs of the Daly River catchment, Northern Territory

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Abstract

This article presents a summary of knowledge for all the known (and predicted) species of freshwater molluscs from the Daly River catchment – a total of 32 species in 11 families. A common theme is that the taxonomy of many of these species is unsettled because it is based only on shells so genetic studies are now necessary to determine biological species for their management and for land use. Five species are considered as endemic to the Daly River catchment and this represents the highest number of endemic/short range taxa for any drainage basin in the Northern Territory. A further three species occur in adjacent countries in Southeast Asia but nowhere else in Australia. There is only one anthropogenically introduced species. Qualitative field observations by us between 1978 and 2019 have not indicated a decline in the abundance of any species, but the plans to develop the region and increase agriculture in the catchment (in particular cotton growing) could pose a long term risk to these environmentally sensitive molluscs.

Introduction

The Daly River catchment is a very large, triangular drainage basin southwest of Darwin in the Northern Territory (Figure 1). With an area between 49,443 km^2 (Stein *et al.* 2014) and 53,198 km^2 (Kirby & Faulks 2004) it is the twenty-first largest basin in Australia (Stein *et al.* 2014). Contiguous with the Daly River catchment are two larger catchments – the Roper River catchment (79,618 km^2) on the east and the Victoria River catchment (78,145 km^2) on the southwest. The Daly River catchment extends to its (single) outlet at the Daly River mouth in the northwestern corner of the catchment into the Timor Sea, and hence is classified as the Timor Sea Drainage Division by the Australian Water Resource Council (Stein *et al.* 2014).

Besides the Daly River itself (Figure 2), the major tributaries in the catchment are the Katherine River, Flora River, Fish River, Fergusson River, Edith River, King River, Dry River and Douglas River. The largest of these tributaries, the Katherine River, has its headwaters in the high-relief sandstone escarpment country of the Arnhem Land plateau, approximately 150 km upstream of the town of Katherine.

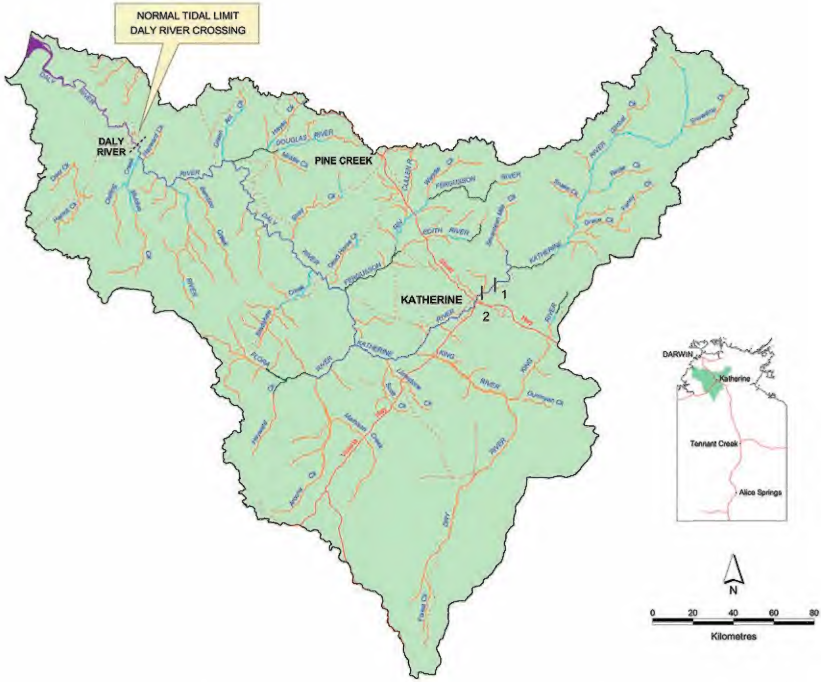

Figure 1. Map of Daly River catchment. Reproduced from *Top End Waterways Project – Daly River Catchment (2020), Map 2. Locality Plan and Dry Season Flows.*

The Daly River is under tidal influence for 68.7 km upstream (measured in a direct line), that is 3 km southeast of Daly River Mission where there is an elevated causeway.

Annual rainfall in the catchment is approx. 1000 mm, with 90% falling between November and May. As a result, discharge at the Daly River mouth is highly seasonal with monsoonal and cyclonic weather producing Wet season flows of up to 2000 m^3s^{-1} at Mt Nancar, 100 km upstream of the Daly River mouth (Stewart-Koster *et al.* 2011). Rainfall is negligible during the Dry season, with the flow in the Daly River and its

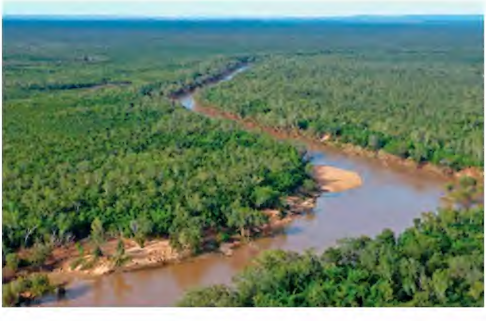

Figure 2. Aerial view of Daly River 125 km southeast of the Daly River mouth. This photograph, which was taken during the 2012 Australian Biological Survey Bush Blitz expedition, shows the Daly River shortly after the end of Wet season (April 2012). The section of the Daly River forms the natural boundary between the Douglas Daly Research Farm and Fish River Station. Note that clearing of native forest upstream contributes to increasing soil erosion and so causes the seasonal discoloration of the water. (Vince Kessner)

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major tributaries supplied predominantly from groundwater. The Tindal Limestone and Oolloo Dolostone aquifers are important groundwater stores providing Dry season flow for parts of the river system. Many of the smaller tributaries cease to flow entirely during the Dry season (Stewart-Koster *et al.* 2011) and the temporary billabongs dry up completely (Figures 9–10).

At no point along their course are any of the aquifers supplying the Daly catchment regulated.

Freshwater molluscs are an important yet often neglected component of Australia's biological diversity (Ponder *et al.* 2020).

This work presents a summary of knowledge for all the known species of freshwater molluscs from the Daly River catchment. It is the result of numerous field trips to the catchment, mostly by VK, over more than 40 years (i.e. between 1978 and 2019). The specimens used for illustration in this article are from VK's collection.

The paragraphs summarising the taxonomy of the species dealt with here are mostly based on the comprehensive Australia-wide website *Australian Freshwater Molluscs* by Ponder *et al.* (Revision 1, 2020), however in a few cases, we have deferred to the global database *World Register of Marine Species* (WoRMS 2020) [which includes many freshwater species nowadays] for names and/or dates of publication, as the entries there are made by specialist editors and are more likely to be accurate. We are acutely aware that the names will change as the result of future taxonomic research.

Australia has based its legislation pertaining to the categorisation of threatened species under the *Environment Protection and Biodiversity Conservation Act,* with the criteria loosely based on the International Union for the Conservation of Nature criteria (Woinarski *et al.* 2007). A more stringent criterion for categorisation of threatened species is given under Northern Territory legislation. The six categories there are Data Deficient, Least Concern, Vulnerable, Endangered, Critically Endangered and Extinct. We note that no species of freshwater mollusc is presently listed under any of the categories (Woinarski *et al.* 2007). Though not formally assessed, we have assigned each species to one of these categories depending on our knowledge and experience. In the Northern Territory there is no existing management program for any freshwater species.

Figures 3–10 (opposite page). The different faces of, and habitats in, the Daly River catchment: **3.** Daly River in the Dry season (July 2005), this section near Bamboo Creek is still under tidal influence. **4.** Ooloo Crossing, looking north (October 2019). **5.** Katherine River, west of Katherine Gorge (August 2018). **6.** Douglas River, lower section of the river runs over limestone bed (September 2019). **7.** Seasonal stream running over rocky bed, Fish River Station (April 2012). **8.** Billabong on Tipperary Station (May 2008). **9.** Leach lagoon, 45 km south of Katherine, after the Wet season (May 1978). **10.** Leach lagoon in the Dry season (October 2020). (Vince Kessner)

Results

Family Neritiliidae

The Neritiliidae is numerically a very small family of microgastropods. The majority of species live in submarine caves (Kano & Kase 2003), so a representative living in the open in freshwater is remarkable.

Neritilia vulgaris Kano & Kase, 2003 (Figure 12)
Taxonomy. *Neritilia vulgaris* was first described from freshwater situations in Irimote and Yaeyama islands, Okinawa, southern Japan. It has subsequently proven to be widely distributed in tropical southeastern Asia. This record for the Daly River is the first, and so far only, for this species in Australia. It is abundant where it occurs.
Habitat. Lives in shallow, permanently flowing water. The substrate is silty sand.
Distribution. Known in Australia only from the Daly River, Bamboo Creek and Browns Creek, but nowhere else outside the Daly River catchment.
Conservation status. Data deficient.
Comments. Although the date of first collection for this species in Australia (1994) is relatively recent, it merely reflects how recently anybody has taken an interest in these microscopic snails. Therefore, the Australian populations of this species is certain to be native rather than an anthropogenic introduction.

Family Neritidae

The Neritidae is a numerically large family of gastropods of which the majority are marine (and in the genus *Nerita*), but there is also a considerable number of tropical brackish and freshwater species in the genera *Clithon, Nereina, Neritina, Neripteron, Neritona, Puperita, Septaria, Theodoxus, Vitta* and *Vittina*. These brackish and freshwater taxa are very poorly represented in tropical northern Australia compared to tropical Asia and Oceania, and Davis & Ponder (2019) hypothesise this is because of the disruption of stream-ocean connectivity in this country.

Neripteron cf. transversecostatum (Schepman, 1919) (Figures 11, 13)
Taxonomy. The genus *Neripteron*, which is numerically large, is characterised by its generally flat shape (some species have wing-like lateral expansions), a large peg on the columella, a black stain on the exterior of the operculum, and a corneous lamella on the upper face of the operculum (Eichhorst 2016). *Neripteron transversecostatum* was first described from the Lorentz River, West Papua. It is similar to, and often considered a junior synonym of, *N. lecontei* (Récluz, 1853), but the research group lead by Y. Kano has verified them to be different species based on molecular and shell differences. This name was applied to the snails from the Daly River by Y. Kano himself (pers. comm. to W. Ponder, May 2020). A future molecular study could show genetic differences at the species level to those in southwestern New Guinea (pers. obs.) so we have used the "cf." convention to indicate our taxonomic uncertainty.
Habitat. Lives in shallow water in freshwater streams under tidal influence. The substrate is logs, leaves and rocks. Apparently individuals gather to graze epiphytes off the surface

of recently fallen leaves (Figure 11). It is abundant where it occurs.

Distribution. Presently known only from a small section of the Daly River between Bamboo Creek and Browns Creek, but not anywhere else outside the Daly River catchment.

Conservation status. Data deficient.

Comments. *Colenuda kessneri* occurs in the same habitat as *Neripteron cf. transversecostatum.*

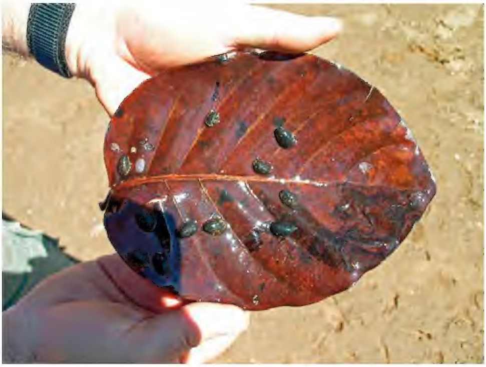

Figure 11. Group of *Neripteron* cf. *transversecostatum in situ* on the upper surface of a submerged leaf of Leichhardt Pine (*Nauclea orientalis*), Bamboo Creek at the junction with the Daly River, 21 July 2016. These individuals had apparently aggregated to graze on the microscopic epiphytes off this fallen leaf. Most of these individuals have egg cases laid by conspecifics on the outside of their shell. (Vince Kessner)

Family Viviparidae

The Viviparidae is a numerically small family of operculum-bearing, exclusively freshwater snails with a worldwide distribution. The family name derives from the ability of its members to bear live young (i.e. viviparous) rather than the more usual method of reproduction by laying eggs (B.J. Smith 1992). Only a few species occur in Australia and these are distributed in the large drainage basins of the central and northern regions. Several species have been introduced into Australia accidentally by humans. None of these introduced species is present in any of the waterways of northern Australia so far, although *Bellamya heudei guangdungensis* does well as an aquarium escapee in man-made ponds in the north (RCW pers. obs.).

Notopala ampullaroides (Reeve, 1863) (Figure 14)

Taxonomy. Stoddart (1982) and B.J. Smith (1992: 83) considered the large-shelled *Notopala ampullarioides* to be a synonym of *N. essingtonensis* (Frauenfeld, 1862), but Ponder *et al.* (2020) have reinstated it as differing from other banded *Notopala* species like *N. essingtonensis* because of its short spire and large aperture, smooth or almost smooth shell, and usually dark colour with often indistinct spiral lines. Further research incorporating both soft part morphology and genetics is required.

Habitat. Lives in flowing rivers. The substrates are *Pandanus aquaticus* roots, or logs, or under large rock slabs. It is abundant where it occurs.

Distribution. Widespread between the Kimberley region in Western Australia and the western section of the Top End in the Northern Territory. Key localities in the Daly River catchment are the Douglas River and the Daly River.

Conservation status. Least concern.

Comments. A relatively large-sized riverine species of viviparid that is common where it occurs. Although the biology of this species has not been studied, its anatomy shows that it is, at least in part, a suspension feeder, using its gill for filtering food from the water like other viviparids, and that it broods its eggs in the pallial oviduct. Brooded young are released sequentially (Stoddart 1982).

Notopala kingi (A. Adams & Angas, 1864) (Figures 15a–c)

Taxonomy. B.J. Smith (1992: 83) considered *Notopala kingi* to be a synonym of *N. waterhousii* (A. Adams & Angas, 1864), but Ponder *et al.* (2020) have reinstated it as differing from other large-shelled *Notopala* species. One synonym is *Vivipara dimidiata* E.A. Smith, 1882. Ponder *et al.* (2020) separated *N. kingi suprafasciata* (Tryon, 1866) as a subspecies of *N. kingi* from the Murray-Darling catchment.

Habitat. Lives in springs, billabongs, waterholes, canals, seasonal swamps and ponds. The substrates are mud or sand, on/or under logs and rocks. It is abundant where it occurs.

Distribution. Widespread from the eastern Kimberley region, through the Northern Territory, to western Queensland. Key localities in the Daly River catchment are the seasonal and permanent billabongs and waterholes on the plains of the Katherine, Daly, Douglas and Fish Rivers.

Conservation status. Least concern.

Comments. The shell is frequently covered with thick algal growth and therefore it is difficult to detect on substrates covered by the same algae or in dense aquatic vegetation (VK pers. obs.).

Family Thiaridae

The Thiaridae is a numerically medium-sized, monophyletic family of operculum-bearing snails that live in the tropical regions of Asia, from Iran and India, Japan, the Malay Archipelago and northern Australia (B.J. Smith 1992). Most are freshwater, with the minority tolerating brackish water. Thiarids are notoriously variable in shell characters so they present enormous taxonomic challenges. This variability has resulted in a great number of (generic and specific) synonyms. Some species are viviparous. Some brood their young to the crawl-away stage in the mantle cavity, so populations can build up numbers rapidly. Glaubrecht *et al.* (2009) made an initial investigation into the systematics of Australian Thiaridae.

Melanoides tuberculata (Müller, 1774) (Figures 16a, b)

Taxonomy. This species exhibits enormous intraspecific variability in shell shape (though it is always elongate and tall-spired), sculpture and colour (Glaubrecht *et al.* 2009). There are at least 22 primary synonyms.

Habitat. Although normally a freshwater snail, this species is very tolerant of brackish water for extended periods, and has been recorded in waters with a salinity of 32.5 ppt. It can live in mangrove forests (such as those at the entrance to Rapid Creek in Darwin; pers. obs. RCW and VK), presumably where there is a thin layer of brackish water on the surface of the mud. It lives in ponds, creeks, springs, dams and canals, on sand or mud. So far, our only records of it in the Daly River catchment are in artificial freshwater ponds, but presumably it also occurs in the saline section of the Daly River near its mouth. It is abundant where it occurs.

Distribution. This species is native to northern Africa and southern Asia, but it has been accidentally introduced in many other tropical and subtropical areas worldwide, including northern Australia where it is now recorded from northern Western Australia, the Northern Territory, throughout Queensland, and northern New South Wales. It has also been accidentally introduced to heated aquaria in colder parts of the world (Wikipedia 2020). A key locality in the Daly River catchment is Springvale Homestead in Katherine.

Conservation status. Least concern. It would be worthwhile to investigate if this introduced species had any negative impacts on native thiarid snails.

Comments. *Melanoides tuberculata* is a very opportunistic and environmentally tolerant species of thiarid that is now widespread through human translocation as well as natural spread. It is the only species of mollusc in the Daly River catchment that we can confidently say has been introduced, albeit accidentally. Conversely, *Melanoides tuberculata* was deliberately introduced into the West Indian island of Martinique in 1983 as a biological control agent for two *Biomphalaria* species which transmit schistosomes to humans because *M. tuberculata* is a known competitor of these snails (Pointier *et al.* 1984). The populations of both *Biomphalaria* species declined rapidly and had disappeared completely by 1985 (Pointier et al. 1989). Nowhere within Australia do densities of *Melanoides tuberculata* match those reported elsewhere; for example densities of 10,000 per m^2 have been reported from the Saint Johns River in Florida (Perera and Walls 1996).

Melasma onca (A. Adams & Angas, 1864) (Figures 17 a, b)

Taxonomy. This species is characterised by its slender, straight, evenly spaced axial ribs always with a chain of grain-like nodules immediately below the suture (Ponder *et al.* 2020). Even though B.J. Smith (1992: 76) placed it as a synonym of *Melanoides tuberculata* based on an examination of the type specimens, it is consistently different (morphologically and genetically) from that species so merits treatment as a separate species.

Habitat. Lives in permanent (flowing) rivers and streams. The substrates are amongst pebbles and stones or on clean sand. It is moderately common where it occurs.

Distribution. Wide ranging throughout the (tropical) section of the Northern Territory, but inland from the coast. Key localities in the Daly River catchment are the Katherine, Flora, Douglas and Daly rivers, and Glass Water Swamp on Litchfield Station.

Conservation status. Least concern.

Comments. Glass Water Swamp eventually drains into the tidal salty section of the Daly River. The water coming off the swamp is very clear, running over a clean sandy bottom and through thick riparian vegetation.

Mieniplotia scabra (Müller, 1774) (Figure 18)

Taxonomy. This ovoid-conical, low-spired species of viviparid has great intraspecific variability in shell form. The whorls are stepped and there are often distinct axial ribs that extend, on the upper part of the whorl, as nodules and (usually short) spines. There are numerous synonyms based on overseas specimens. The genus *Mieniplotia* is genetically rather distinct from all other thiarids (Glaubrecht *et al.* 2009), and is monospecific.

Habitat. Lives in permanently flowing freshwater rivers and streams. The substrates are silty mud, on water weeds, and in sand.

Distribution. Patchy in the northern (tropical) section of the Northern Territory and northeastern Queensland; predominantly coastal. Possibly accidentally introduced anthropogenically, and still spreading. It is moderately common where it occurs. In the Northern Territory it is not as common as it is in Asia, for example in Indonesia (VK pers. obs.). Key localities in the Daly River catchment are the Douglas River and the Daly River.

Conservation status. Least concern.

Comments. This species is considered one of the most successful invasive species in many parts of the world (Thompson *et al.* 2009). It presently has an extremely large distribution – from India, through southeastern Asia and parts of the Western Pacific. This distribution is a combination of a natural range plus accidental anthropomorphic introductions. Moreover, Mienis (2011) has suggested another vector for its dispersal – migrating birds. Recent reports indicate that *Mieniplotia scabra* has become established in the Mediterranean Basin (Greece) (Cianfanelli *et al.* 2016).

Sermyla carbonata (Reeve, 1859) (Figure 19)

Taxonomy. Lentge-Maaß *et al.* (2020) have confirmed that *Sermyla venustula* (Brot, 1877) is a synonym of *S. carbonata* so there is only a single species of *Sermyla* in Australia, not two as previously considered. Crawling juveniles with up to seven shell whorls are released from the subhaemocoelic brood pouch of the female. Adults often have strong axial ribs crossed by weak spiral grooves (Lentge-Maaß *et al.* 2020). Juvenile shells of *S. carbonata* are as diverse in shape and sculpture as are adult shells (VK pers. obs.).

Habitat. Lives in running water in small streams, rivers and springs, but not in non-flowing waters. Also in freshwater rivers under tidal influence. The substrate is sand, mud or rocks. It is moderately common where it occurs.

Distribution. Using genetics, Lentge-Maaß *et al.* (2020) have now resolved *Sermyla carbonata* as a single endemic Australian species. Its distribution is wide, but patchy, from northern Western Australia, throughout the Northern Territory (including central Australia), to northern Queensland. An isolated population occurs in Howard Springs south of Darwin. Key localities in the Daly River catchment are the Daly River and Bamboo Creek.

Conservation status. Least concern.

Comments. We have found *Sermyla carbonata* to be relatively uncommon in the Daly River catchment. It is apparently more common in river systems draining into the Gulf of Carpentaria.

Stenomelania denisoniensis (Brot, 1877) (Figure 20)

Taxonomy. This is a variable species with a long, slender shell and relatively small aperture. It is smooth or sculptured with some spiral threads and distinct axial growth lines. It usually has an angled shoulder just below the suture, and this shoulder is strong in some individuals (Ponder *et al.* 2020). Glaubrecht *et al.* (2009) speculate that a new generic name might be necessary based on unpublished molecular data.

Habitat. Lives in small streams, dams, springs, lagoons, rivers, sometimes in extremely shallow water. The substrates are sand, mud, rocky substrates, or amongst aquatic vegetation. It is common where it occurs.

Distribution. Australian endemic. From central Western Australia (Pilbara region), through the northern half of the Northern Territory, to southeastern Queensland. Key localities in the Daly River catchment are the Douglas and Daly Rivers, and Bamboo Creek.

Conservation status. Least concern.

Comments. A thiarid with an extensive distribution throughout tropical and subtropical Australia (i.e. the northern half of the continent).

Thiara australis (I. & H.C. Lea, 1851) (Figure 21)

Taxonomy. The strong axial ribs which feature prominently on the apical half of the last whorls are characteristic of this species. The whorls are sometimes weakly to moderately shouldered or sometimes evenly convex (Ponder *et al.* 2020), but never spinose. It was previously known in Australia as *Melania australis* I. & H.C. Lea, 1851, and two unused synonyms with type localities in Australia are *M. cerea* Brot, 1860 and *M. decussata* Brot, 1862. Glaubrecht *et al.* (2009) speculated that a new generic name might be necessary for this taxon based on unpublished molecular data.

Habitat. Lives in running streams and rivers. The substrates are sand and rocks, amongst water vegetation. It is abundant where it occurs.

Distribution. Wide ranging from northern Western Australia, throughout coastal and subcoastal Northern Territory, to northern Queensland (Gulf of Carpentaria). In Queensland, *Thiara australis* occurs only in the rivers draining into the Gulf of Carpentaria. Key localities in the Daly River catchment are the Flora, Douglas and Daly rivers, Bamboo Creek, and Glass Water Swamp on Litchfield Station.

Conservation status. Least concern.

Comments. Embryos are brooded in a brood pouch in the head and released as crawling juveniles (Maaß & Glaubrecht 2012).

Family Assimineidae

This is a numerically large family of very small operculate snails. Assimineids live predominantly in freshwater and brackish habitats, although some fully terrestrial and some fully marine species are also known. The morphological distinction between it and Tateidae and Hydrobiidae (if they are separate families themselves) is not clear at present.

***Assiminea* sp.** (Figure 22)

Taxonomy. A very small species. In comparison to *Taiwanassiminea bedaliensis*, the shell is slightly smaller, more slender/conical, and the two brown bands on the last whorl are relatively much wider. This species is mentioned by Fukuda *et al.* (2014) and by Hallan & Fukuda (2015), and genetic sequencing indicates it does not match any known species (A. Hallan pers. comm.).

Habitat. The habitat is shaded areas on moist sand or mud above the waterline. It is common where it occurs.

Distribution. Seemingly patchy and localised. This undescribed assimineid is found living on mud only near the junction of Bamboo Creek with the Daly River and on wet sand along the banks of Browns Creek. Both creeks are freshwater streams under tidal influence. It has been also collected on mud on the bank of a small tidal creek approx. 32 km downstream on Litchfield Station. It is common where it occurs.

Conservation status. Data deficient.

Comments. Until the taxonomy of this species is resolved it is impossible to know if it is an Australian native species or an introduced species.

Taiwanassiminea bedaliensis (B. Rensch, 1934) (Figure 23)

Taxonomy. The shell of this very small species has five brown spiral bands on the whorls, of which three are more distinct than the others (Ponder *et al.* 2020). It is currently not known whether this species is native to northern Australia (it is only known from the Douglas River, Northern Territory) or introduced from tropical Asia. However, some morphological evidence, such as the relatively larger shells and the apparent lack of a subsutural groove in the Australian shells, suggests that the Australian taxon may be native, and possibly even a distinct species (Ponder *et al.* 2020). It is illustrated by Hallan & Fukuda (2015).

Habitat. Lives on the banks of streams wherever it occurs – both in Australia and in Asia. The microhabitat is seepages and permanently wet mud. It is abundant where it occurs.

Distribution. Originally described from Java, it has now been reported from many parts of the world. In Australia, it is known only from the Douglas River.

Conservation status. Data deficient.

Comments. As mentioned above, this might be a species of *Taiwanassiminea* endemic to the Daly River catchment rather than the very widespread *T. bedaliensis.*

Family Bithyniidae

Members of this numerically small, operculate family of snails occur in fresh and slightly saline water worldwide. It appears that the family has radiated in freshwaters in northern Australia wherein members occur predominantly in backwaters and billabongs.

Gabbia smithii (Tate, 1882) (Figure 24)

Taxonomy. This species is ovate-conical to conical in shape, and fine growth lines and microscopic spiral striae are often present. An umbilicus is absent in both adults and juveniles (Ponder 2003).

Habitat. Lives in billabongs, small streams, pond, road scrapes, flood channels and swamps. The substrate is aquatic vegetation or on mud/sandy mud. It is absent from the larger rivers. It is abundant where it occurs. Key localities in the Daly River catchment are Leach Lagoon (45 km south of Katherine), and seasonal and permanent billabongs and waterholes on the plains running along the Katherine, Daly, Fish and Douglas rivers, and the billabongs and swamps on Litchfield Station.

Distribution. It occurs throughout tropical parts of northern Western Australia (the Kimberley region), the northern half of the Northern Territory, and northern Queensland. This range is the largest of any of the 21 Australian species of *Gabbia* (with the possible exception o*f G. campicola* in Queensland and New South Wales).

Conservation status. Least concern.

Comments. We are surprised that none of the other species of *Gabbia* known from coastal northern Australia is recorded from the Daly River catchment, such *as G. adusta, G. beecheyi, G. clathrata, G. kessneri, G. lutaria, G. microcostata* and *G. tumida*. Certainly more than one *Gabbia* species can exist sympatrically; for example, *G. adusta* co-occurs with *G. smithii* at Warloch Ponds, near Elsey Cemetery south of Mataranka, and *G. lutaria* occurs with *G. smithii* in Jinumum Gorge, Keep River National Park, Victoria River District (VK pers. obs.).

Family Clenchiellidae

Members of this family are microscopic in size and few in number. Their flattened, disc-shaped shells belie their relationships with the relatively tall-spired hydrobiids. Nonetheless, clenchiellids were treated as a tribe or a subfamily of Hydrobiidae until they were elevated to separate family status by Ponder *et al.* (2014). The Clenchiellidae is actually more closely related to the Calopiidae, Tornidae and Iravadiidae than to the Hydrobiidae.

Coleglabra nordaustralis Ponder *et al.,* 2014 (Figure 24)

Taxonomy. The following description of the shell is reproduced from Ponder *et al.* (2020). Shell minute (up to 1.9 mm in diameter); whorls with few dorsally distinct spiral cords and indistinct spirals on base, strong spiral keels absent; aperture almost circular, peristome simple, prosocline, external varix absent; operculum simple with no peg or white deposit on the inner side. The shell of *Coleglabra nordaustralis* is similar to that of *Colenuda kessneri* in having a few spiral threads on the dorsal surface and weaker spirals on the base, lacking spiral keels and in having a relatively narrow umbilicus and a low to moderate spire. The shell of *Coleglabra* differs most obviously from that of *Colenuda* in having a simple peristome, whereas that of *Colenuda* has a wide, shallow excavation and it lacks an external varix. The edge of the aperture, when viewed dorsally, is convex in *Coleglabra.*

Habitat. Lives in a section of the perennial Douglas River flowing over a limestone basement. Living specimens were collected by washing the roots of *Melaleuca* trees. It is abundant where it occurs.

Distribution. Known only from the Douglas River. Endemic to the Douglas River.

Conservation status. Data deficient.

Comments. A second species of *Coleglabra* lives in a freshwater lake in Papua New Guinea.

Colenuda kessneri Ponder *et al*., 2014 (Figure 26)

Taxonomy. The following description of the shell is reproduced from Ponder *et al.* (2020). Shell minute (1.9 mm in diameter), with low spire and open umbilicus narrower than in other genera. Whorls with fine spiral threads, strong spiral cords or keels absent. Aperture nearly circular, peristome with shallow indentation dorsally, prosocline, very weak external varix usually present. Operculum simple with no peg or white smear to plate-like deposit on inner surface. The characters that distinguish *Colenuda kessneri* from the similar-looking *Coleglabra nordaustralis* are given above.

Habitat. Lives in shallow, running water, freshwater rivers and creeks under tidal influence. The substrate is silty sand. It is superabundant where it occurs locally.

Distribution. Known only from a short section of Daly River, between Bamboo Creek and the nearby junction of Browns Creek with Daly River. Endemic to the Daly River.

Conservation status. Data deficient.

Comments. A minute endemic gastropod present in large numbers. It occurs sympatrically and syntopically with *Neritilia vulgaris* and *Lentidium dalyfluvialis*.

Family Lymnaeidae

This is a numerically medium-sized family of small- to medium-sized freshwater snails which prefer slow or non-flowing waters (such as billabongs, dams and ponds). Its distribution is worldwide. Several European species have been introduced anthropogenically into southern Australia where they are now thriving. None of these introduced species is present in any of the river catchments of northern Australia so far, although *Pseudosuccinea columella* does well as an aquarium escapee in man-made ponds in the north (RCW pers. obs.) This species is undesirable because it is a known vector of Liver Fluke (*Fasciola hepatica*).

Bullastra vinosa (A. Adams & Angas, 1864) (Figure 27)

Taxonomy. This species was previously known as *Austropeplea lessoni* (Deshayes, 1830) throughout its range. However, the southern Australian *Bullastra lessoni* (as it is now known) is distinguished from the more northern *Bullastra vinosa* by its lower spire and more globose shape (Ponder *et al.* 2020), but this shell-based distinction has not been tested genetically. This hypothesis implies *Amphipeplea phillipsi* A. Adams & Angas, 1864, *Limnaea angasi* G.B. Sowerby II, 1872, *Limnaea deshayesii* G.B. Sowerby II, 1872, *Amphipeplea queenslandica* Clessin, 1886, *Peplimnea lilmera* Iredale, 1943, *Peplimnea vinolenta* Iredale, 1943 and *Peplimnea caurina* Iredale, 1943 are junior synonyms of *B. vinosa*.

Habitat. Lives in lakes, billabongs, seasonal pools, ponds, canals and swamps. The substrates are water vegetation, or directly on the mud. It is abundant where it occurs.

Distribution. It is widely distributed throughout the northern half of Australia. Key localities in the Daly River catchment are Moon Billabong on Litchfield Station, the billabongs on the plains between the Daly and Douglas rivers, Douglas Daly Research Farm, Leach Lagoon near Katherine, and Naenayee Lagoon on Tipperary Station.

Conservation status. Least concern.

Comments. Very common. Individuals are sometimes observed crawling on the mud above the waterline. In stagnating pools it can float upside-down at the water's surface (VK pers. obs.), or even emerge completely out of the water on the upper surface of leaves of water lilies (Keith and Terina Saunders pers. obs. at Lorella Springs Station in the central western Gulf of Carpentaria). One assumes this abnormal behaviour was brought about by low oxygen levels in the water at the end of the Dry season.

Family Planorbidae

This is numerically the largest and easily the most diverse of freshwater snails morphologically. It has a worldwide distribution. The family is represented by a wide variety of forms such as medium-sized high-spired sinistral shells, or small-sized planispiral shells, or medium-sized limpet-like shells (B.J. Smith 1992). Planorbids are the dominant group of freshwater molluscs numerically and ecologically in many freshwater habitats (B.J. Smith 1992). Planorbids are confined to waters of low salinity and are usually associated with water weeds or algae on which they feed. Several species have been introduced into Australia, by accident anthropogenically. None is present in any of the waters of northern Australia so far, though *Planorbella duryi* does well as an aquarium escapee in man-made ponds in the north (RCW pers. obs.). Many planorbid genera and species have been described from shell features alone and so they are in need of genetic analysis and taxonomic revision. There are many forms which do not fit the presently described taxa (e.g. in the genera *Amerianna*, *Gyraulus* and *Glyptophysa* in Australia).

Amerianna compar Iredale, 1943 (Figure 28)

Taxonomy. The genus *Amerianna* requires a major taxonomic revision. At present the identification of the species is based on shell characters alone and all workers admit that intermediate forms exist amongst all the recognised species. These intermediate forms are not included in this study. This nominal species is rather small and it has a stepped spire as the last whorl is offset from the plane of the other whorls. The periphery is sharply angled, usually with a weak to moderate carina, as in the larger *A. reevii* (Ponder *et al.* 2020).

Habitat. This species lives on the banks of small streams and billabongs, road scrapes and temporary ponds. The substrates are rocks, logs and aquatic water vegetation. It is also frequently found on submerged *Pandanus aquaticus* leaves. It is common where it occurs.

Distribution. Wide ranging across tropical Australia, from Western Australia, through the Northern Territory and Queensland, to northern New South Wales. Key localities in the Daly River catchment are Leach Lagoon near Katherine, Reynold River, the billabongs on the floodplains at Litchfield Station (e.g. Darkies and Moon Billabongs), and the permanent and seasonal billabongs on Douglas Daly Research Farm and Fish River Station.

Conservation status. Least concern.

Comments. The type locality is the Lennard River, Western Australia.

Amerianna carinata (H. Adams, 1861) (Figure 29)

Taxonomy. This nominal species is the most well known in the genus. It is larger than *Amerianna compar*. It has a medium-sized shell with a flat-topped spire with the edge of the whorls acutely angled as though cut with a knife, but they are not keeled. The area immediately below the angulation is evenly convex (Ponder *et al.* 2020).

Habitat. It lives in seasonal swamps, ponds, billabongs and lagoons. It seems to prefer habitats relatively close to the coast. The substrate is shallow water on rocks, logs and leaves of aquatic vegetation. It is abundant where it occurs.

Distribution. Wide ranging across tropical Australia, from Western Australia (possibly extending to the islands of the eastern Indian Ocean), through the Northern Territory, to southeastern Queensland. Key localities in the Daly River catchment are Darkies Billabong (Litchfield Station), the permanent and seasonal billabongs on the Douglas Daly Research Farm, and Red Lily Lagoon near Daly River Mission.

Conservation status. Least concern.

Comments. A species of *Amerianna*, matching the morphotype of *A. carinata* was discovered in 1987 along the banks of the Galion River on Marinique island, in the West Indies, having been accidentally anthropogenically introduced (Pointier 1996). It rapidly colonised the whole island but remained restricted to particular micro-habitats sheltered from seasonal flooding along the river banks (Pointier 2001).

Amerianna reevii (A. Adams & Angas, 1864) (Figure 30)

Taxonomy. This nominal species has a medium-sized shell with a flat-topped spire, with the edge of the whorls strongly angled and keeled. The area below the angulation is slightly concave. Synonyms are *Physa truncata* H. Adams, 1861 (non Bourguignat, 1856) and *Amerianna gabrieli* Cotton, 1942.

Habitat. It lives in larger billabongs. Unlike the other species of *Amerianna*, *A. reevii* seems to prefer large water bodies (VK pers. obs.). The substrates are aquatic vegetation, wood, submerged *Pandanus aquaticus* leaves, and directly on the mud. It is moderately common where it occurs.

Distribution. Limited to the northern section of the Northern Territory and the eastern Kimberley region. Key localities in the Daly River catchment are Moon Billabong on Litchfield Station and the permanent billabongs on the Douglas Daly Research Farm.

Conservation status. Least concern.

***Amerianna* sp.** (Figure 31)

Taxonomy. This taxon has a medium-sized shell with an elevated spire. The spire is considerably higher than in any of the other three *Amerianna* species covered here. Each whorl is strongly keeled. In having an elevated spire, it resembles *A. cumingi* (H. Adams, 1861) (with synonym *Physa bonushenricus* A. Adams & Angas, 1864, but which seems not to occur in the Daly River catchment). However *A. cumingi* is keeled, whereas this species lacks keels.

Habitat. It lives in billabongs, swamps, ponds and dams. The substrates are mud, wood, aquatic plants and *Pandanus aquaticus* leaves. It is abundant where it occurs.

Distribution. Appears to be widespread in the Northern Territory. Similar shaped morphotypes have also been collected in northern Western Australia and northern Queensland. Key localities in the Daly River catchment are Darkies Hole, Litchfield Station, Naenayee Lagoon and Tipperary Station.

Conservation status. Least concern.

Comments. This taxon appears to be more common in the Finnis River/Dundee Beach area than in the Daly River catchment.

Bayardella johni (J.B. Burch, 1977) (Figure 32)

Taxonomy. *Bayardella johni* is a distinctive planorbid because it possesses heavy spiral ridges consisting of periostracal extensions on its whorls. The only other species in the genus *Bayardella*, *B. cosmeta*, which comes from the Murray-Darling catchment, has a narrower spire and a less distinct shoulder compared to *B. johni*.

Habitat. It lives in ponds, small (frequently) seasonal (ephemeral) streams, rock pools and springs. It is absent from large rivers and billabongs. It lives attached to rocks. It is abundant where it occurs.

Distribution. Wide ranging between northern Western Australia, throughout the Northern Territory, to the eastern Gulf of Carpentaria (i.e. northern Queensland). Information on key localities in the Daly River catchment is not available due to lack of collecting. It has been found in the streams along the Victoria Highway towards Timber Creek, just outside the Daly River catchment.

Conservation status. Least concern.

Comments. Although we have not found *Bayardella johni* in the Daly River catchment to date, we are confident that it occurs here, and so have included it in this article.

Glyptophysa jukesii (H. Adams, 1861) (Figure 33)

Taxonomy. The taxonomy of the genus *Glyptophysa* is poorly understood and in need of revision. *Glyptophysa jukesii* has a most unusual shape for the genus with a low rounded spire. It has a pronounced columella fold at the base of aperture, and small adult size.

Habitat. Lives in shallow billabongs, swamps, seasonal pools or small streams with little water movement. The substrates are aquatic vegetation, logs and rocks. It is moderately common where it occurs.

Distribution. Widely distributed in the Northern Territory with extensions into the eastern and southwestern Kimberley regions (where it is less common). The key locality in the Daly River catchment is Hayes Creek, a tributary of the Douglas River.

Conservation status. Least concern.

Comments. The type locality is Port Essington, Cobourg Peninsula. Most of the sites at which *Glyptophysa jukesii* occurs are seasonal rocky pools along the Stuart Highway near Hayes Creek. It is much more common south of Katherine (e.g. a few kilometres past Leach Lagoon), where the streams form part of the Roper River drainage system.

Glyptophysa novaehollandica (Bowdich, 1822) (Figures 34a, b)

Taxonomy. *Glyptophysa novaehollandica* is the most common and most variable species in the genus in Australia in terms of its shape and periostracal development (i.e. periostracal hairs and spirals can be present or completely absent), even within a single population. There are many named forms that are presently considered as synonyms of *G. novaehollandica.*

Habitat. As with most planorbids, this species lives in billabongs, swamps, and slowly flowing streams and rivers. The substrates are aquatic plants, wood, submerged *Pandanus aquaticus* leaves, and directly on the mud. It is abundant where it occurs.

Distribution. This species is found throughout mainland Australia, with the exception of the southern half of Western Australia and the western section of South Australia. It also occurs in Tasmania. Key localities in the Daly River catchment are Darkies Hole and other billabongs on Litchfield Station, Leach Lagoon (Katherine area), Naenayee Lagoon, Tipperary Station, Red Lily Lagoon near Daly River Mission, Fish River Station, and the billabongs on the Douglas Daly Research Farm.

Conservation status. Least concern.

Comments. *Glyptophysa novaehollandica* is the most common planorbid in the Daly River catchment, often being found where nothing else (at least no other mollusc) lives.

Helicorbis australiensis (E.A. Smith, 1882) (Figure 35)

Taxonomy. This species differs from the historically familiar small discoidal planorbids of the genus *Gyraulus* by its strongly overlapping whorls and peripheral keel that is not centrally positioned on the whorls. The shell is smooth, shining, and dark red-brown to pale amber when alive. It is small and flat, with a small to medium sunken spire and a narrow to medium umbilicus. Some individuals have small internal lamellae (Ponder *et al.* 2020). Brown (1981) noted that the taxonomy of this genus *Helicorbis* requires revision. This species was previously known as *Segmentina australiensis* E.A. Smith, 1882.

Habitat. Lives mostly in stagnant situations in billabongs, ponds and lagoons. The substrates are wood and plants, and directly on the mud. It can be abundant locally.

Distribution. Very wide ranging – from the eastern Kimberley region, throughout the northern half of the Northern Territory, to eastern Queensland. It also occurs in inland New South Wales, South Australia and Tasmania. Key localities in the Daly River catchment are Leach Lagoon (Katherine area), the Douglas River, and the billabongs on the Douglas Daly Research Farm.

Conservation status. Least concern.

Comments. *Helicorbis australiensis* appears to be a hardy species that is particularly able to cope with seasonal changes. One particularly good example is Leach Lagoon, where towards the end of the Wet season large number of *H. australiensis* are present. The lagoon is shallow and seasonal, drying out shortly after the Wet season ends (Figure 10). It fills up again (depending on the start of the Wet season) around the end of November (Figure 9). The snails appear quite suddenly and in good numbers shortly after the lagoon is full. This same ability to build up populations rapidly when favourable conditions prevail also applies to the other sympatric and syntopic species such as *Gabbia smithii*, and the species of *Glyptophysa* and *Amerianna*.

Gyraulus essingtonensis (E.A. Smith, 1883) (Figure 36)

Taxonomy. Though the small, discoidal planorbids of Australia resemble those of Africa, they are generically different – those of Australia are in the genus *Gyraulus*, whereas those from Africa are in the genera *Afrogyrus* and *Ceratophallus* (Brown 1998). According to Brown (2001: 48) there are only two species of *Gyraulus* in the Northern Territory and Western Australia. The shells of this species are very variable in shape and size. A synonym of *G. essingtonensis* is *Glyptanisus coranus* Iredale, 1934.

Habitat. Lives in billabongs, ponds, swamps, lakes, lagoons, dams, and slowly flowing streams. The substrates are under rocks and on aquatic vegetation. It can be superabundant locally.

Distribution. Wide ranging throughout the tropical north of Australia, from northern Western Australia, throughout the Northern Territory (including Cobourg Peninsula in the north and central Australia in the south, to northern Queensland. Key localities in the Daly River catchment are Red Lily Lagoon near Daly River Mission, the billabongs along the Daly and Douglas rivers on the Douglas Daly Research Farm, and the billabongs on Litchfield Station.

Conservation status. Least concern.

Comments. The type specimens were collected at Port Essington, Cobourg Peninsula, and they were presented to the British Museum by the Earl of Derby.

Gyraulus hesperus (Iredale, 1943) (Figure 37)

Taxonomy. Brown (2001) has given a full account of this species. Its shell is strongly keeled medially with the angle being strongest on the last half whorl of large specimens.

Habitat. Lives in billabongs, swamps, gutters, ponds, dams and slowly flowing streams. The habitats are aquatic vegetation, submerged wood, *Pandanus aquaticus* leaves, and other solid substrates – including the undersurface of rocks. It can be superabundant locally.

Distribution. Wide ranging throughout the tropical north of Australia, from northern Western Australia, throughout the Northern Territory, to northern Queensland. Key localities in the Daly River catchment are Leach Lagoon (near Katherine), the Katherine River, the billabongs along the Daly and Douglas Rivers, the billabongs on Litchfield Station, Naenayee Lagoon, Tipperary Station, Kathleen Falls and Flora River.

Conservation status. Least concern.

Comments. It is interesting that some species of small planorbids should be locally superabundant.

Leichhardtia sisurnius (Hedley, 1918) (Figure 38)

Taxonomy. Shells of this species are relatively small, sinistral and subglobose, with evenly rounded whorls, the spire is low, the aperture is elliptical, the parietal lip gently curved and the parietal callous adheres to body whorl, the anterior end of the aperture is constricted and thus it sometimes forms a short canal, and an umbilicus is present (Ponder *et al.* 2020). Although the shell resembles that of species of *Glyptophysa*, the body whorl is crossed by spiral rows of striae and wrinkles which support the periostracal hairs. This species is readily recognised by the shell surface microsculpture consisting of fine raised points commonly coalescing into continuous wavy lines and the constricted anterior end of the aperture which sometimes forms a short canal.

Habitat. Lives in small seasonal streams, ponds, billabongs and swamps. It apparently prefers stationary waters or very slowly running streams. The substrates are bedrock, isolated stones and logs and, less frequently, directly on the mud. It is common where it occurs.

Distribution. Wide ranging across the tropical section of northern Australia, from the Kimberley region, through the Northern Territory, to the Gulf of Carpentaria in northwestern Queensland. Key localities in the Daly River catchment are seasonal pools along the Stuart Highway near Hayes Creek.

Conservation status. Least concern.

Comments. The illustrated specimen was collected in very shallow water in the middle of a road during a monsoon.

Pettancylus petterdi (R.M. Johnston, 1879) (Figure 39)

Taxonomy. This small, enigmatic, limpet-shaped planorbid differs from the southeastern mainland Australian *Pettancylus tasmanicus* in having a more elongate shell. *Pettancylus petterdi* sometimes develops a septum restricting the aperture and/or a detached cap-like structure at the shell apex (Ponder *et al.* 2020).

Habitat. Lives in rivers, streams and billabongs, ponds, lagoons and canals. The substrates are (on top of or underneath) rocks, logs, and leaves of aquatic vegetation. It is common where it occurs.

Distribution. Wide ranging throughout Australia. Key localities in the Daly River catchment are the Douglas River, the billabongs on the Douglas Daly Research Farm, the billabongs on Litchfield Station, and the Fergusson River (Litchfield National Park).

Conservation status. Least concern.

Comments. *Pettancylus petterdi* attaches tightly to substrates the same way as *Bayardella johni* or marine limpets do. Because the shells are small and fragile, care must be taken when removing them or they will break. The safest way to keep them intact is to put the substrate into a container filled with salty water or diluted alcohol, and after a few minutes they drop off.

Family Hyriidae

Known colloquially as freshwater mussels, but not related to either true mussels (Mytilidae) or false mussels (Dreissenidae), freshwater mussels have large shells (or very large shells as in the eastern Australian *Cucumerunio novaehollandiae*). The hyriids are relics of Gondwana, represented in Australia and New Guinea by the ancestral Velesunioninae and in Australia and New Zealand by the Hyriinae (Tribe Hyridellini) (Walker *et al.* 2014). Representatives of the Hyriidae occur in most river catchments in Australia. Oddly however, no member of the family is present on the Tiwi Islands (Willan & Jones 2019). The present taxonomy is based on shells and (to some extent) on anatomy, and does not take into account how the shells are affected by local environmental conditions. At present, the conservation of Australasian freshwater mussels is hindered by the lack of a taxonomic framework that employs molecular data as a complement to shell characters, larval forms and internal anatomy (Walker *et al.* 2014).

Lortiella opertanea Ponder & M. Bayer, 2004 (Figure 40)

Taxonomy. Shell relatively elongate and narrowly hatchet-shaped with the posterior end flaring, the anterior end from the umbo relatively short and the margin rounded. Posterior end relatively long and almost truncate but rounded, ventral margin straight to concave. Dark olive brown, bluish to yellowish to dull golden brown internally. This species is not as narrowly elongate as *L. rugata* and is more elongate and compressed than

L. froggatti. As in all species of the genus *Lortiella*, the juveniles lack distinct sculpture on the beak and shell surface (Ponder & M. Bayer 2004; Ponder et al. 2020).

Habitat. Lives only in permanently flowing rivers. The substrate is under large boulders and rock slabs. It can be common locally.

Distribution. This species is endemic to the Daly River and its major tributaries (e.g. Katherine River, Douglas River).

Conservation status. Data deficient.

Comments. Those individuals living beneath slabs of rock frequently cluster in small groups consisting of juveniles through to large adults (RCW and VK pers. obs.).

Velesunio angasi (G.B. Sowerby II, 1867) (Figure 41)

Taxonomy. The shell is compressed, relatively elongate and the posterior expanded and usually winged. The ventral margin usually straight, rarely convex or slightly sinuate. The width/length ratio is greater than 55% (Ponder *et al.* 2020). The taxonomy of this species, plus the supposedly only other species of *Velesunio* from northern Australia, *V. wilsonii*, is presently under revision using genetic techniques (Hugh Jones pers. comm.).

Habitat. Very broad; lives in rivers, seasonal/permanent streams, ponds, billabongs, irrigation canals, swamps, lakes and lagoons. Individuals live buried (or partially buried) in sand or mud.

Distribution. Wide ranging throughout northern tropical Australia. It is common where it occurs. Key localities in the Daly River catchment are the Katherine, Daly and Douglas rivers, King River, Reynolds River and Hayes Creek.

Conservation status. Least concern.

Comments. In clear water *Velesunio angasi* can be found by following the tracks left in the substrate by individuals as they move. The presence of buried mussels themselves is indicated by a narrow slit or a hole left by the retracted siphons.

Family Corbulidae

This is numerically a medium-sized family of smallish bivalves that live (often in great densities) just beneath the surface of soft substrates attached by a few byssal threads to sand grains. The majority of the species are marine and some tolerate polluted habitats. A few genera tolerate brackish water, but only the genus *Lentidium* tolerates completely fresh water.

Lentidium dalyfluvialis Hallan & Willan, 2010 (Figure 42)

Taxonomy. Hallan & Willan (2010) described two endemic Australian species of *Lentidium*, a remarkable freshwater genus of corbulids – *L. dalyfluvialis* from the Daly River and *L. origolacus* a now-extinct species from the former Lake Carpentaria. The genus *Lentidium* is "remarkable" because of its active lifestyle, strong foot and thin shell, as well as being far more equivalve and equilateral than the majority of species within the family Corbulidae.

Habitat. Lives in shallow water in permanently flowing sections of the Daly River. The section where it has been found alive is the bend where Browns Creek enters the Daly River some 60 km upstream from its mouth, but still under tidal influence with 1–2 m

semidiurnal tides. The substrate consists of quartz grains overlain with a veneer of mud. *Lentidium dalyfluvialis* buries shallowly in clean- to silty-sand. Though normally infaunal and endobyssate, *L. dalyfluvialis* is capable of rapid movement and active burrowing (RCW pers. obs.). It is superabundant where it occurs (i.e. its density is approx. 1000 per m^2).
Distribution. Endemic to (a short stretch of) the Daly River.
Conservation status. Data deficient.
Comments. Other molluscs that occur in the same habitat as *Lentidium dalyfluvialis* are *Thiara australis*, *Neritilia vulgaris* and *Colenuda kessneri*.

Family Cyrenidae [previously generally known as Corbiculidae]
This is a numerically small family of large, long-lived, thick-shelled bivalves. Most species live in fresh water or are estuarine (i.e. mangrove forests) in habitat. Given that the largest species that live in mangrove forests (in the genus *Geloina*) represent a significant food source for traditional Aborigines yet the species are potentially long-lived, there is a great need to undertake a taxonomic study that incorporates soft part morphology and genetics.

Corbicula australis (Deshayes, 1830) (Figure 43)
Taxonomy. This species is apparently widely distributed in the Australian continent (Ponder *et al.* 2020). Given this enormous geographic spread and considerable intraspecific variability, it is possible that cryptic species may eventually be separated out from *C. australis*. This species was previously placed in the genus *Corbiculina* which is now regarded as a synonym of *Corbicula*. Synonyms at species level are *Cyclas nepeanensis* Lesson, 1831, *Cyrena debilis* Gould, 1850, *Corbicula ovalina* Deshayes, 1855, *Corbicula minor* Prime, 1861, *Corbicula angasi* Prime, 1864, *Corbicula rivina* Clessin, 1877, *Corbicula sublaevigata* E.A. Smith, 1882, *Corbicula deshayesii* E.A. Smith, 1882, *Corbicula desolata* Tate, 1887, *Corbicula faba* Bullen, 1904, *Corbiculina permena* Iredale, 1943, *Corbiculina esculenta* Iredale, 1943, *Corbiculina mussoni* Iredale, 1943, *Corbiculina subovalina* Iredale, 1943, *Corbiculina aramita* Iredale, 1943, *Corbiculina semara* Iredale, 1943 and *Corbiculina finkeana* Iredale, 1943.
Habitat. Lives buried shallowly in sand and gravel in flowing rivers, canals and streams. Its greatest abundance is in riffle habitats in streams. The substrate is clean- to silty-sand and gravel. It is occasionally found embedded in soil and among roots of trees in the banks of smaller streams. It is abundant where it occurs. Key localities in the Daly River catchment are the Katherine, Flora, Daly and Douglas rivers.
Distribution. Wide ranging throughout mainland Australia, but not Tasmania; coastal and inland.
Conservation status. Least concern.
Comments. *Corbicula australis* often occurs in the same localities as freshwater mussels but they are always separated by habitat and substrate – *C. australis* occurs in streams in sandy substrates, whereas freshwater mussels occur in billabongs in muddy substrates.

Discussion

The list consists of 32 species of freshwater molluscs in 11 families and 26 genera, all but one (*Bayardella johni*) recorded by us from the Daly River catchment. We are surprised that there is presently not more neritid, lymnaeid, planorbid or *Gabbia* species, or any species of *Musculium* living in the catchment. [But we note there is one lot of *Musculium* in the Australian Museum mollusc collection identified as *M. tasmanicum tasmanicum* from the Douglas River (approx. 1 km east of the junction with the Daly River, on the Douglas Daly Research Farm) collected by VK in Aug 1995. We suspect this identification might be erroneous and based on a juvenile *Corbicula australis*.]

Five species of freshwater molluscs are considered as endemic to the Daly River catchment – *Assiminea sp., Coleglabra nordaustralis, Colenuda kessneri, Lortiella opertanea* and *Lentidium dalyfluvialis*. A further three species occur nowhere else in Australia but the Daly catchment – *Neritilia vulgaris*, *Neripteron cf. transversecostatum*, *Taiwanassiminea bedaliensis*. With the exception of these eight species, the remaining 24 freshwater molluscs are widely distributed within the rest of the Northern Territory and/or across tropical northern Australia. Some species are present only in flowing streams (as indicated under the Habitat subheading for each species); the remaining species can be present in both permanent and seasonal bodies of water.

Although not the largest catchment in the Northern Territory, the Daly is significant in terms of biodiversity of freshwater molluscs. It has the highest number of endemic and short-range species of any catchment in the Northern Territory. The largest, the Roper River catchment, has fewer endemic species, but an unusual composition of species (i.e *Gabbia adusta*, *Aviassiminea palitans*, the enigmatic *Posticobia brazieri*, *Notopala tricincta*, *Alathyra pertexta wardi* and *Musculium* sp.). The next largest catchment, the Victoria River catchment, has at least four endemic species (i.e. *Gabbia lutaria, G. tumida, Lortiella rugata* and *Velesunio wilsoni*) (possibly even more depending on how many subterranean hydrobiid species occur in Gregory National Park). We should mention that the Adelaide River catchment, which is one of the smaller catchments in the region, has three endemic species (*Gabbia microcosta, G. kessneri* and *Kessneria papillosa*). So it seems that for freshwater molluscs in northern Australia, endemicity is not directly proportional to catchment size.

The Daly River catchment is coming under increasing pressure from development – 5.6% of the catchment's savannah woodland has already been cleared. Other intensifying pressures are grazing, hot and too frequent fires, feral animals, intensive horticultural activities (particularly cotton growing), urban development, water extraction for drinking and irrigation, wastewater discharge from Katherine and Pine Creek, high metal discharge from the Mt Todd Mine, intensive agriculture, fertilisers and herbicides, and increases in nitrite runoff (Schult & Townsend 2012; pers. obs.). Our qualitative observations on the freshwater molluscs, which now span almost 40 years, have not shown a long term decline in the numbers or distribution of any particular species. This situation is in stark contrast to the land snails within the catchment specifically where several species are now formally classified as Threatened (Woinarski *et al.* 2009; Braby *et al.* 2011). We suggest it is time to use some freshwater molluscs as biological indicators to monitor the health of the Daly River catchment into the future.

Acknowledgements

Were it not for the generous assistance of Winston Ponder, Anders Hallan and Matthias Glaubrecht, we would have little idea of the taxonomy of some of the species in the problematic families of Thiaridae, Assimineidae and Planorbidae. We are grateful to Keith and Terina Saunders for recounting their observations of live *Bullastra vinosa* fully emerged out of the water on top of lily leaves.

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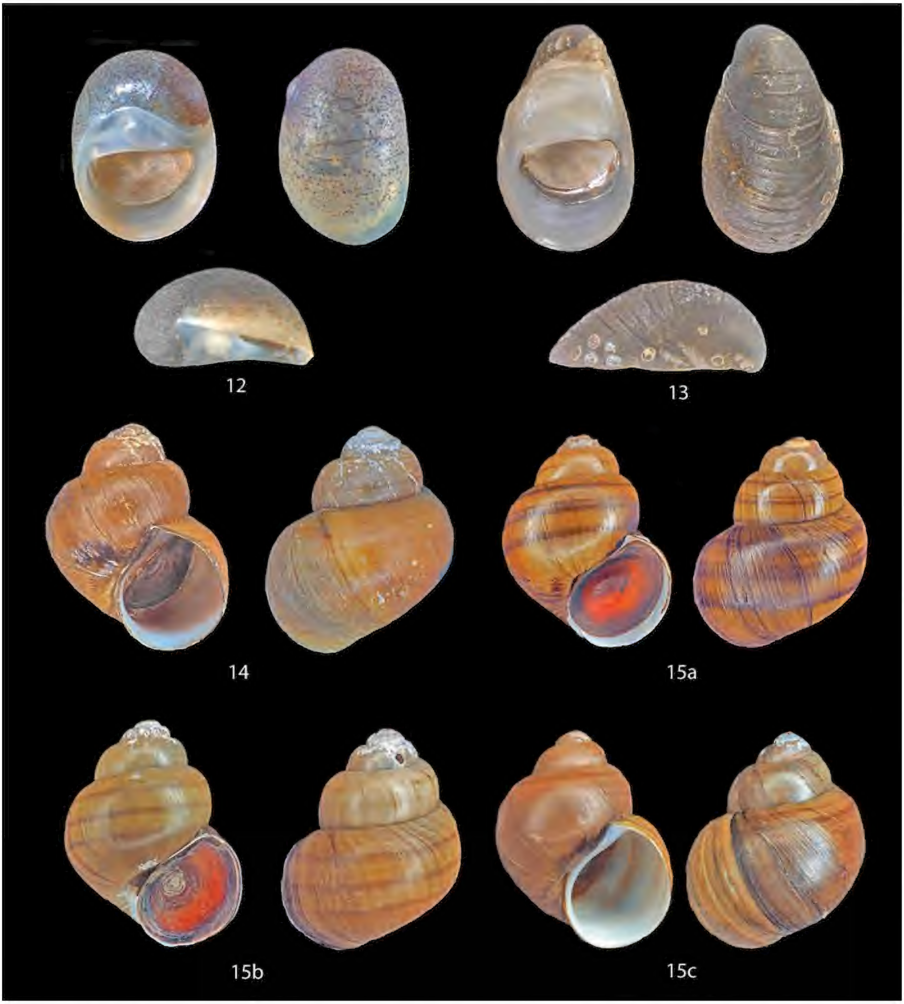

Figures 12–15. Representative shells of the families Neritidae and Viviparidae. **12.** *Neritilia vulgaris*. Bamboo Creek at the junction with the Daly River. Height 1.8 mm. width 3.0 mm. **13.** *Neripteron* cf. *transversecostatum*. Bamboo Creek at the junction with the Daly River. Height 6.0 mm. width 16.0 mm. **14.** *Notopala ampullarioides*. Daly River downstream from Oolloo Crossing. Height 26.1 mm. width 20.0 mm. **15.** *Notopala kingi*. **a.** Fish River Station. Height 26.7 mm. width 18.9 mm. **b.** Permanent billabong 3.6 km SW. of Douglas Daly Research Farm. Height 25.0 mm. width 18.5 mm. **c.** Colour form named *Vivipara dimidiata*. illustrated specimen is from the type locality – Victoria River. Height 22.0 mm. width 18.2 mm. (Vince Kessner)
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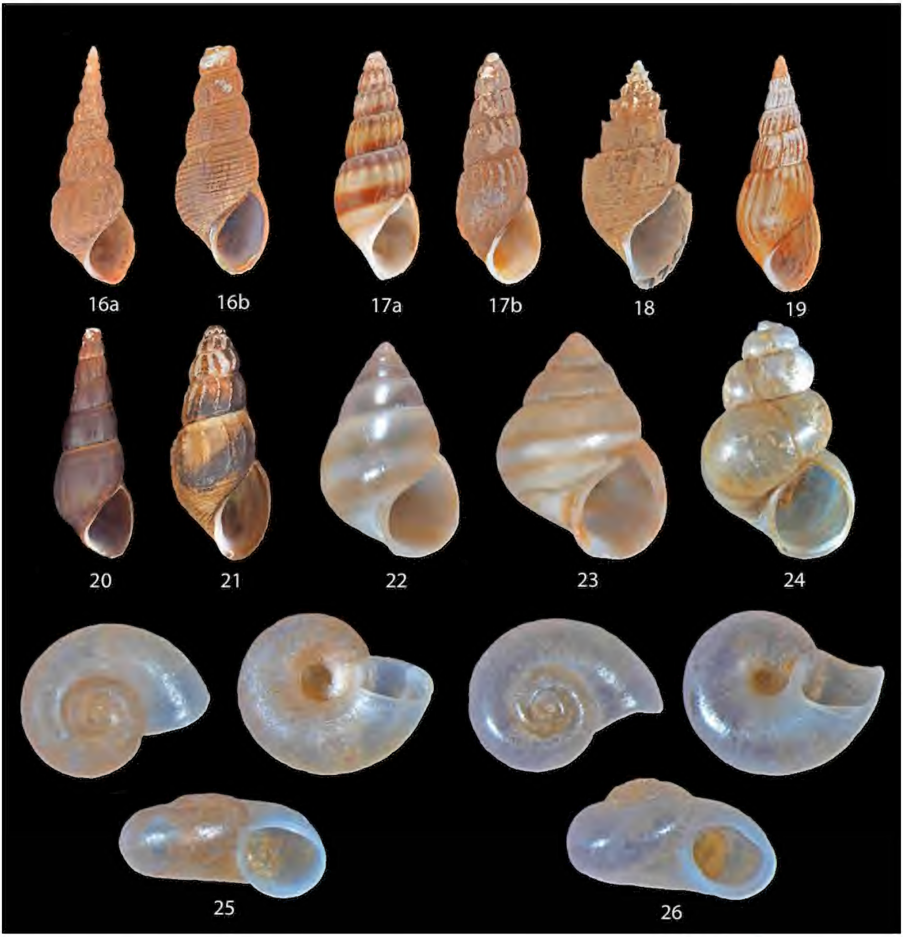
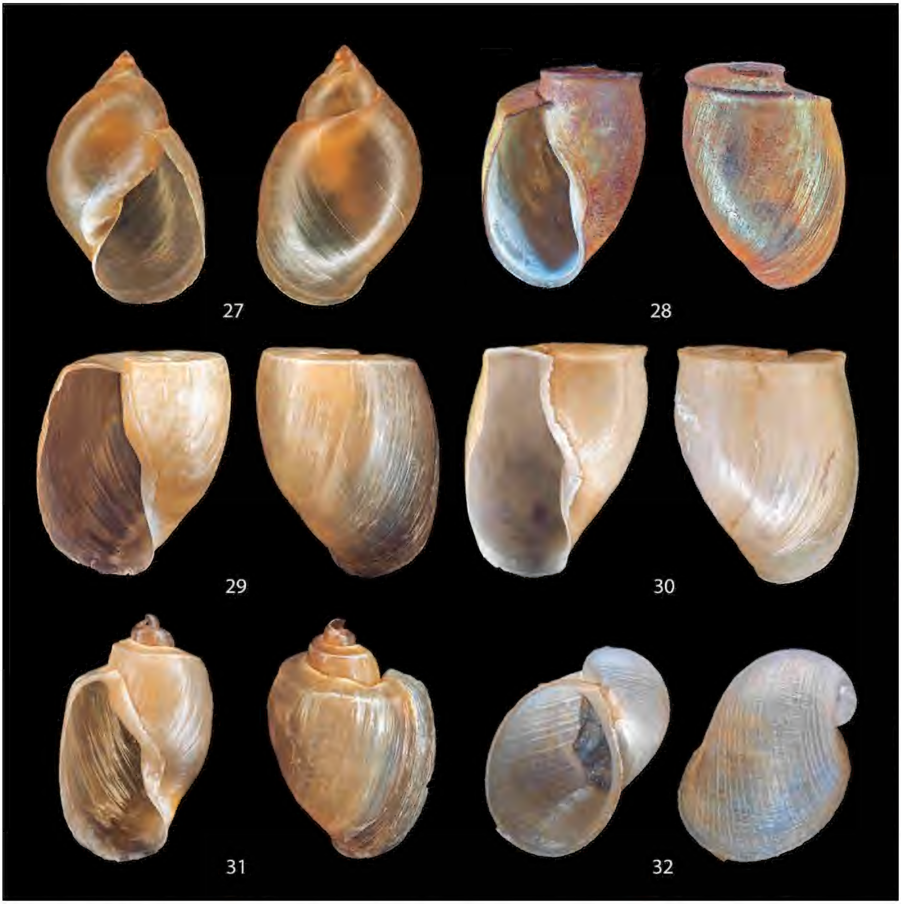
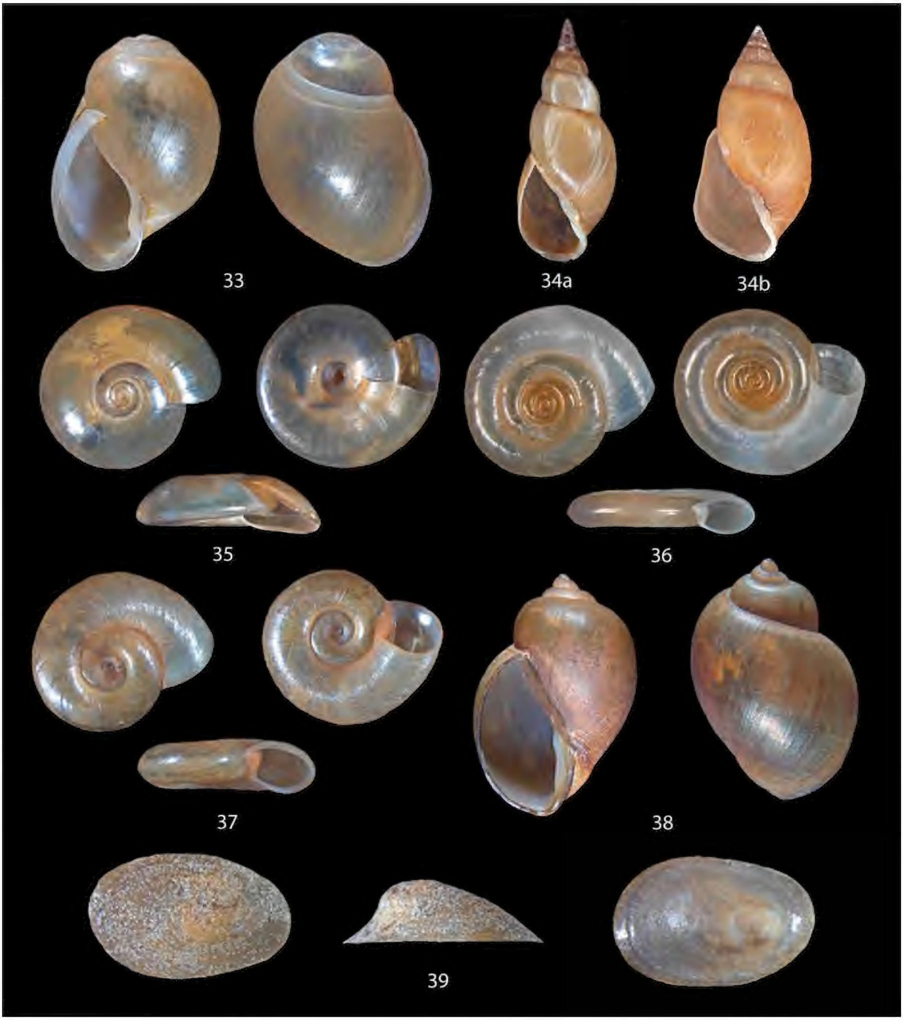


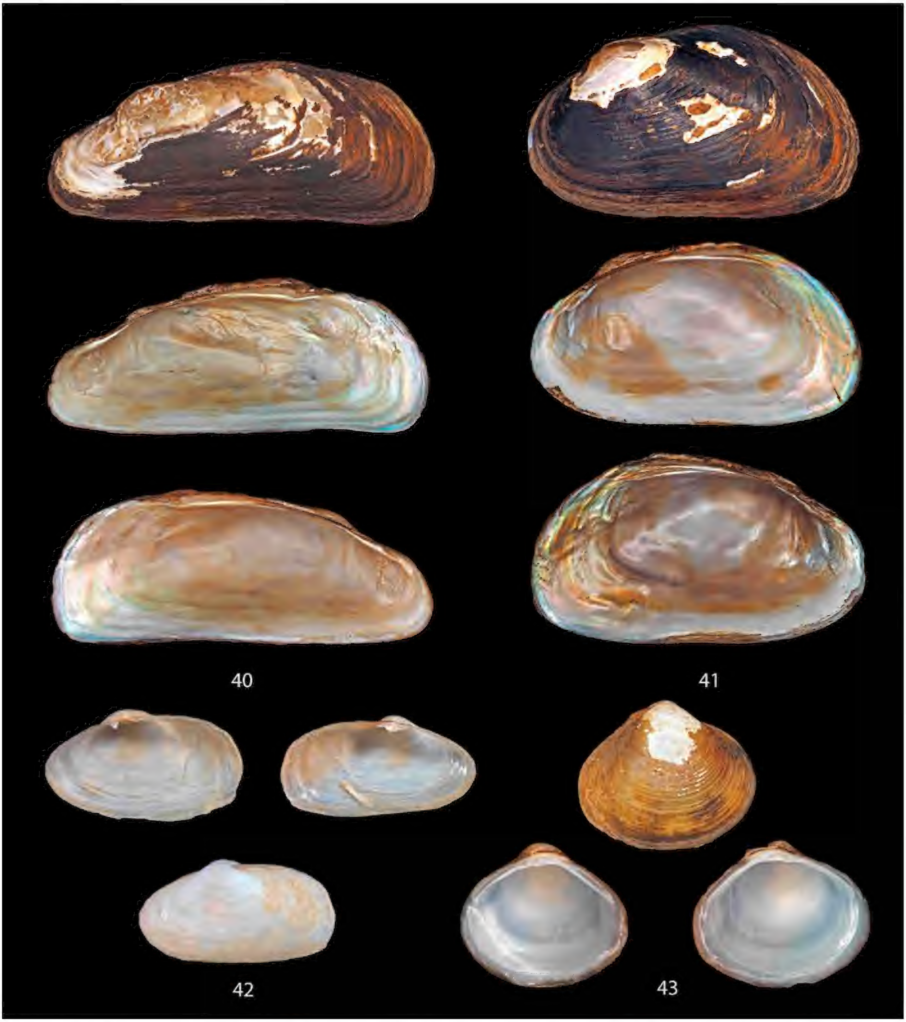
Figures 16–26. Representative shells of the families Thiaridae. Assimineidae. Bithyniidae and Clenchiellidae. **16.** *Melanoides tuberculata.* **a.** Spring at the Springvale Homestead. Katherine. Height 22.0 mm. width 7.0 mm. **b.** George Brown Botanical Gardens. Darwin (specimen included to show intraspecific variability). Height 20.2. width 8.2 mm. **17.** *Melasma onca.* **a.** Daly River downstream from Oolloo Crossing. Height 27.5 mm. width 9.9 mm. **b.** Flora River. near Kathleen Falls. Height 27.6 mm. width 9.6 mm. **18.** *Mieniplota scabra.* Daly River at Oolloo Crossing. Height 18.7 mm. width 9.3 mm. **19.** *Sermyla carbonata.* Daly River Crossing. near Daly River Mission. Height 23.5 mm. width 8.5 mm. **20.** *Stenomelania denisoniensis.* Bamboo Creek at the junction with Daly River. Height 35.5 mm. width 11.9 mm. **21.** *Thiara australis.* Daly River near Oolloo Crossing. Height 23.9 mm. width 9.9 mm. **22.** *Assiminea* sp. Bamboo Creek at the junction with Daly River. Height 3.3 mm. width 2.1 mm. **23.** *Taiwanassiminea bedaliensis.* Douglas River. approx. 1 km from the junction with Daly River. Height 3.7 mm. width 2.8 mm. **24.** *Gabbia smithii.* Seasonal channel parallel to Douglas River. near Oolloo road. Height 6.8 mm. width 3.5 mm. **25.** *Coleglabra nordaustralis.* Douglas River near the crossing to Tipperary Station. Height 0.8 mm. width 1.8 mm. **26.** *Colenuda kessneri.* Bamboo Creek at the junction with Daly River. Height 0.8 mm. width 1.6 mm. (Vince Kessner)



Figures 27–32. Representative shells of the families Lymnaeidae and Planorbidae. **27.** *Bullastra vinosa*. Red Lily Lagoon. near Daly River Mission. Height 17.9 mm. width 11.0 mm. **28.** *Amerianna compar*. Reynolds River. ca. 1.5 km SW. of Neds Knob. Height 7.5 mm. width 5.1 mm. **29.** *Amerianna carinata*. Darkies Hole. Litchfield Station. Height 15.0 mm. width 11.5 mm. **30.** *Amerianna reevii*. Moon Billabong. 5.1 km SW. of Litchfield Homestead. Litchfield Station. Height 12.4 mm. width 9.3 mm. **31.** *Amerianna* sp. Naenayee Lagoon. Tipperary Station. Height 17.4 mm. width 11.9 mm. **32.** *Bayardella johni*. Dingo Spring Creek on Victoria Highway near Timber Creek. Height 3.9 mm. width 2.9 mm. (Vince Kessner)



Figures 33–39. Representative shells of the family Planorbidae. **33.** *Glyptophysa jukesii*. Seasonal pond east of Stuart Highway just north of Hayes Creek. Height 6.7 mm. width 5.4 mm. **34.** *Glyptophysa novaehollandica*. **a.** Darkies Hole. Litchfield Station. Height 22.0 mm. W: 11.4 mm. **b.** Red Lily Lagoon. near Daly River Mission. Height 27.4 mm. width 11.0 mm. **35.** *Helicorbis australiensis*. Leach Lagoon. 45 km south of Katherine. Height 2.0 mm. width 6.4 mm. **36.** *Gyraulus essingtonensis*. Kathleen Falls. Flora River. Height 1.9 mm. width 7.8 mm. **37.** *Gyraulus hesperus*. Douglas River at crossing to Tipperary Station. Height 1.1 mm. width 3.5 mm. **38.** *Leichhardtia sisurnius*. Seasonal pond east of Stuart Highway just north of Hayes Creek. Height 11.0 mm. width 7.3 mm. **39.** *Pettancylus petterdi*. Douglas River on crossing to Tipperary Station. Height 1.9 mm. width 2.9 mm. (Vince Kessner)



Figures 40–43. Representative shells of the families Hyriidae. Corbulidae and Cyrenidae. **40.** *Lortiella opertanea.* Katherine River. western side of the waterhole near Katherine Gorge. Height 30.0 mm. width 73.0 mm. **41.** *Velesunio angasi*. Katherine River. western side of the waterhole near Katherine Gorge. Height 30.1 mm. width 54.0 mm. **42.** *Lentidium dalyfluvialis.* Daly River at the junction with Brown's Creek. Height 5.0 mm. width 9.0 mm. **43.** *Corbicula australis.* Daly River. 22 km SW. of Florina Station Homestead. Height 15.5 mm. width 18.3 mm. (Vince Kessner)

Observations on the gastropod prey of *Chicoreus capucinus* (Gastropoda: Muricidae) in Darwin Harbour mangroves

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Abstract

Seven opportunistic field observations within mangrove forests in Darwin Harbour revealed that the muricid snail *Chicoreus capucinus* feeds upon relatively large, mobile gastropods and seemingly engages in higher rates of aggregative feeding (prey-sharing) behaviour than its counterparts in Southeast Asia. Field observations and evidence of prey-sharing from drill holes recorded on dead shells indicate that aggregative feeding by *C. capucinus* is associated with at least three gastropod prey species. A record of attempted cannibalism and multiple incidences of aggregative feeding suggest the availability and accessibility to gastropod prey is somehow limited in Darwin Harbour mangroves. Further detailed studies are, however, needed in order to prove this supposition.

Introduction

The predatory muricid snail *Chicoreus capucinus* is a common epifaunal component of Indo-west Pacific mangrove forests (Houart 1992; Wells & Bryce 2000; Lozouet & Plaziat 2008) and is one of the few gastropod predators present in substantial numbers in mangroves (Tan & Oh 2003). Like other muricids, *C. capucinus* feeds by drilling a small, countersunk hole into the shell of its prey through a combination of the scraping action of the radula and softening secretions produced by the accessory boring organ. Field studies from Southeast Asia show that *C. capucinus* is highly skilled in handling prey from both hard (e.g. rocks, mangrove trunks and prop roots) and soft (i.e. mud, muddy sand) substrates (Tan & Oh 2003; Tan 2008), and that its diet consists mainly of barnacles (Nielsen 1976; Tan & Oh 2003; Ng *et al.* 2008) and a variety of bivalve and gastropod molluscs (Gribsholt 1997; Wells *et al.* 2001; Tan & Oh 2003; Tan 2008).

Amongst molluscan prey, epifaunal and shallow infaunal bivalves are typically the largest and principal taxa consumed by *C. capucinus* (Berry 1975; Middelfart 1996; Gribsholt 1997; Tan & Oh 2003; Tan, 2008), and indeed teredinid bivalves are consumed in Darwin Harbour (Richard Willan pers. obs.). The gastropods preyed upon by *C. capucinus* are generally considerably smaller than the bivalves, comprising mainly small, slow moving taxa such as rissooidean, neritoidean and cerithioidean snails (Wells *et al.* 2001; Tan & Oh 2003; Tan & Oh 2008). Among cerithioids, the mud-creeping genus *Pirenella* (previously *Cerithidea*) apparently forms a major dietary component (Wells *et al.* 2001; Tan 2008). Tan

& Oh (2003) noted *C. capucinus* preying upon one of the largest of all mangrove snails *Telescopium telescopium,* but the *Telescopium* was only 11 mm long. Therefore, the earlier report by Wells *et al.* (2001) of *C. capucinus* eating *Pirenella* with shells up to 28 mm in length is apparently the record for the largest gastropod prey item.

Aggregating behaviour is often conspicuous in *C. capucinus* inhabiting mangroves, where snails form breeding clusters under prop roots and on large woody debris (Gribsholt 1997; Wells *et al.* 2001; pers. obs.). However, aggregative feeding or prey-sharing (i.e. multiple predators feeding simultaneously on the one prey item) is seemingly rare (Tan & Oh 2003; Tan 2008), or unreported (Gribsholt 1997; Wells *et al.* 2001) for this species. Both Tan & Oh (2003) and Tan (2008) found from the many hundreds of *C. capucinus* individuals they observed feeding in mangroves and on mudflats directly in front of mangrove forests, less than 1% of all predator-prey interactions involved prey-sharing. Additionally, despite *C. capucinus* being a voracious and versatile predator of molluscs, cannibalism is currently unrecorded (Wells *et al.* 2001; Tan & Oh 2003; Tan 2008).

This note reports *C. capucinus* attacking and consuming large mud-creeping potamidid snails and two other species of gastropods in mangrove forests in Darwin Harbour. Among these records, multiple incidences of aggregative feeding by *C. capucinus* are presented based on field observations and there is evidence of prey-sharing from dead, drilled shells. Furthermore, a record of attempted cannibalism is also reported for the species.

Field observations

During numerous vegetation surveys conducted between May 2015 and November 2019, opportunistic field observations were made of *C. capucinus* actively feeding on gastropod prey in mangrove forests throughout Darwin Harbour. In addition to field observations, dead gastropod shells with evidence of drilling by *C. capucinus* were also collected. During this almost four and a half year period, four gastropod species –*Terebralia semistriata, Telescopium telescopium, Nerita balteata* and *Ellobium aurisjudae* – were recorded as prey of *C. capucinus* (Table 1). Amongst these records, *C. capucinus* was associated in prey-sharing interactions with three of the four species.

Gastropod prey

Of the two incidences of *C. apucinus* preying upon the mud-dwelling potamidid *Terebralia semistriata,* both were recorded in large open stands of *Avicennia marina* trees surround by a *Rhizopora stylosa* mangrove forest. The first observation was of an adult *C. capucinus* drilling the ventral surface of the upper shell spire of an adult *T. semistriata* measuring approximately 65 mm in shell length (SL) (Figure 1). Closer inspection revealed the prey was in the later stages of paralysis, with the head-foot relaxed and the shell aperture partially exposed. The second interaction included prey-sharing, whereby two mature individuals of *C. capucinus* were feeding simultaneously on an adult *T. semistriata*

Table 1. Field observations on the gastropod prey of *Chicoreus capucinus* collected between May 2015 and November 2019 in various mangrove forests throughout Darwin Harbour. Aggregative feeding (prey-sharing) is based on live field observations and drill holes recorded on dead shells (inferred).

Date of observation	Location	Site co-ordinates	Prey species	Aggregative feeding
10 May 2015	Western side of *A. marina* forest, East Point mangrove boardwalk.	12° 24.526'S, 130° 49.837'E	*Terebralia semistriata*	No
15 December 2015	Eastern side of *A. marina* forest, East Point mangrove boardwalk.	12° 24.530'S 130° 49.868'E	*Terebralia semistriata*	2 x *C. capucinus*
8 September 2017	Adjacent to GEP corridor, Wickham Point Road	12° 32.925'S, 130° 53.723'E	*Nerita balteata* (dead shell)	2 x *C. capucinus* (inferred)
5 December 2017	Adjacent to GEP corridor, Wickham Point Road	12° 32.925'S, 130° 53.723'E	*Telescopium telescopium*	No
13 February 2018	Approx. 820 m west of algae farm, Channel Island Road	12° 35.038'S, 130° 55.886'E	*Chicoreus capucinus*	No
			Ellobium aurisjudae (dead shell)	2 x *C. capucinus* (inferred)
25 October 2018	Power & Water access Road, Jones Creek, Channel Island Road	12° 33.935'S, 130° 53.722'E	*Ellobium aurisjudae* (dead shell)	2 x *C. capucinus* (inferred)
11 November 2019	Approx. 200 m NW of Dinah Beach Boat Ramp	12° 26.786'S, 130° 51.073'E	*Nerita balteata*	2 x *C. capucinus*

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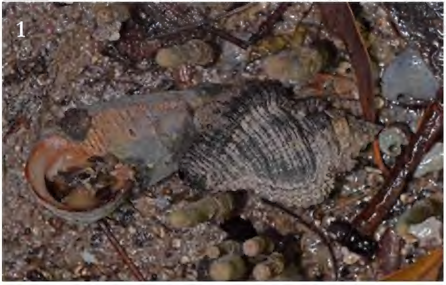

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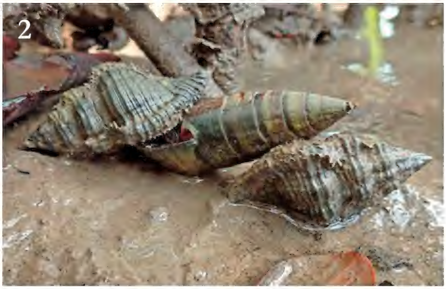

Figures 1–2. *Chicoreus capucinus* feeding on *Terebralia semistriata* at the East Point mangrove site, Darwin Harbour. **1.** *C. capucinus* drilling the upper shell spire of an adult *T. semistriata* (65 mm SL). **2.** Aggregative predation of an adult *T. semistriata* (67.5 mm SL) by two *C. capucinus* snails simultaneously. (Adam Bourke)

(67.5 mm SL) (Figure 2). This aggregative predation involved one *C. capucinus* attacking the prey through the shell's aperture and the other individual drilling at the suture between the upper whorls on the dorsal shell surface.

The mud-dwelling potamidid *Telescopium telescopium* was the largest prey eaten by *C. capucinus* in Darwin Harbour, with a mature live specimen of 77 mm shell length recorded (Figure 3). This single observation of an adult *C. capucinus* (56 mm SL) drilling the dorsal shell of this prey was recorded within a dense *Ceriops australis*-dominated forest at an estimated tidal elevation of 6.4–6.6 m. This upper tidal zone represents the maximum distributional limit of *C. capucinus* in Darwin Harbour mangrove forests (pers. obs.). Recent anecdotal evidence from field observations on dead, drilled shells occupied by the mangrove hermit crab *Clibanarius longitarsus* suggests predator-prey interactions between *C. capucinus* and *T. telescopium* are infrequent but do occur in local mangrove forests.

The two records of *C. capucinus* preying upon the tree-climbing nerite snail *Nerita balteata* incorporate a single field observation and an inference of predation from a dead shell. In the same *Ceriops australis*-dominated forest as the previous interaction, a dead shell of a subadult *N. balteata* 34 mm in shell height (SH) was found with two drill holes approximately arranged posteriorly and anteriorly along the centre line of the dorsal shell (Figure 4). Based on the dimensions and architecture of the drill holes, it was deduced that the neritid had been preyed upon by two individuals of *C. capucinus*. The second field observation involved prey-sharing, whereby two mature individuals of *C. capucinus* were seen feeding simultaneously upon a subadult *N. balteata* (27 mm SH) along the upper tidal margin of a partially closed *Rhizophora stylosa* forest. This interaction involved *C. capucinus* attacking

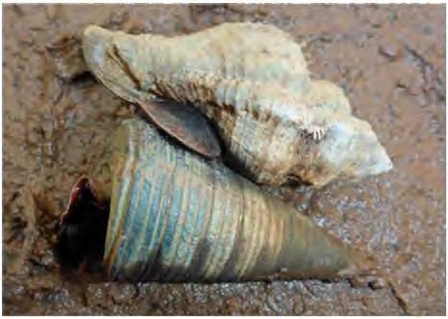

Figure 3. A mature *Chicoreus capucinus* (56 mm SL) preying on *Telescopium telescopium* (77 mm SL) in the *Ceriops australis*-dominated forest. (Adam Bourke)

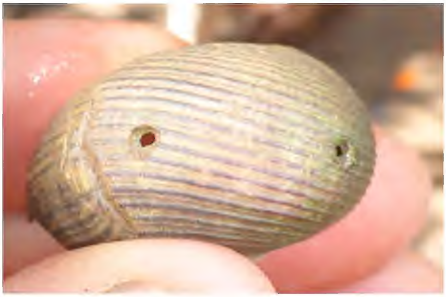

Figure 4. Evidence of aggregative feeding on a shell of *Nerita balteata* (34 mm SH) collected in the *Ceriops australis*-dominated mangrove forest. (Adam Bourke)

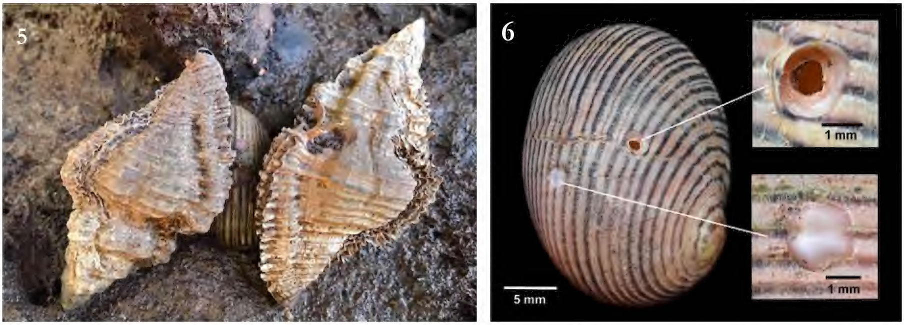

Figure 5–6. Aggregative feeding by *Chicoreus capucinus* on *Nerita balteata* in the *Rhizophora stylosa* mangrove forest. **5.** Two *C. capucinus* individuals simultaneously attacking *N. balteata*; one drilling the dorsal shell surface, the other attacking the prey through the shell aperture. **6.** Shell of the subadult *N. balteata* (27 mm SH) showing the drill hole and an unsuccessful drill mark on the dorsal shell surface. (Adam Bourke)

the prey through the shell aperture at the edge of the shelly operculum while the other individual drilled the dorsal shell surface (Figure 5). Inspection of the *N. balteata* shell showed a fresh, unsuccessful drill hole on the dorsal surface, suggesting one of *C. capucinus* individuals had repositioned itself on the prey (Figure 6).

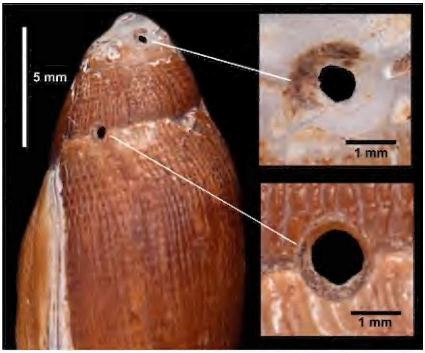

Figure 7. Drill holes on the freshly dead shell of *Ellobium aurisjudae* (23.7 mm SL) collected inside a rotting tree trunk in a *Rhizophora stylosa/Bruguiera parviflora* mangrove forest. (Adam Bourke)

Two records of *C. capucinus* preying upon the woody debris-associated snail *Ellobium aurisjudae* are inferred from dead shells collected on the mangrove forest floor. In a *Rhizophora stylosa/Bruguiera parviflora*-dominated forest a freshly dead shell of a juvenile *E. aurisjudae* (23.7 mm SL) was found within a large, rotting tree trunk with two drill holes on the dorsal shell surface. One hole was positioned at the suture between the penultimate and body whorl slightly towards the aperture while the other was drilled at the midline on one of the apical whorls. Both holes had similar outline diameters, however the perforation of the inner shell wall was markedly different (Figure 7). The second dead shell of *E. aurisjudae* was also a juvenile (21.5 mm SL) specimen and was collected from within a fallen and decaying branch in an open *Rhizophora stylosa*-dominated forest. This old, corroded shell also had two drill holes, one on the ventral shell surface in the centre of the body whorl, and a larger hole set posteriorly on the dorsal surface adjacent the columella. Due to its poor condition, the shell was accidentally destroyed during transportation.

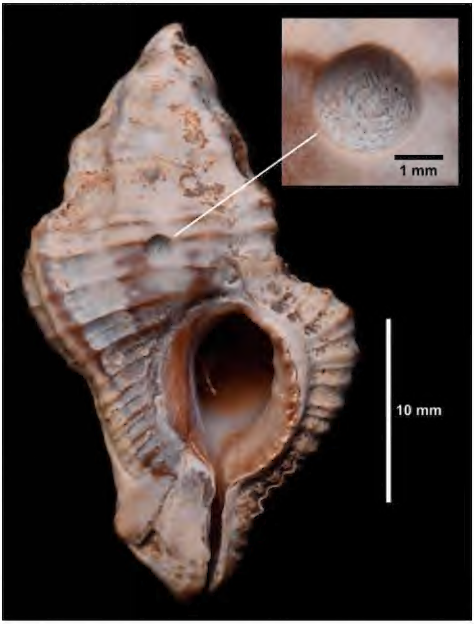

Figure 8. Evidence of attempted cannibalism on the body whorl of small adult *Chicoreus capucinus* (45.2 mm SL) collected from inside a rotting tree trunk in a *Rhizophora stylosa/Bruguiera parviflora* mangrove forest. (Adam Bourke)

Cannibalism

In the same rotting trunk as the freshly dead *E. aurisjudae* shell, a small adult *C. capucinus* with evidence of cannibalism was collected alive under a large sheet of peeling tree bark.

The individual had a worn, bleached shell (45.2 mm SL) and possessed a single drill mark 2.2 mm in diameter, positioned almost centrally on the ventral surface of the body whorl (Figure 8). Based on the size and architecture of the drill mark, it was concluded that an unsuccessful attempt of predation by a larger conspecific had occurred.

Discussion

These field observations of *C. capucinus* feeding upon large gastropod prey wonderfully complement Tan & Oh's (2003) and Tan's (2008) assertion that the species is indeed a versatile and successful predator of intertidal molluscs. The current record of *C. capucinus* attacking an adult *T. telescopium* at the upper limit of its tidal distribution not only illustrates the voraciousness of the species, but also demonstrates its ability in overcoming large, mobile prey.

It appears that in Darwin Harbour's mangrove forests, aggregative feeding by *C. capucinus* snails is not uncommon. Prey-sharing is apparently rare amongst populations of *C. capucinus* in Southeast Asia (Tan & Oh 2003; Tan 2008). By contrast, in Darwin Harbour aggregative predation was associated with three gastropod prey species – *Terebralia semistriata, Nerita balteata* and *Ellobium aurisjudae*. These interactions suggest that group feeding by *C. capucinus* is likely to be a recurrent behaviour in the harbour. Prey-sharing has been reported in a number of muricids (e.g. Brown & Alexander 1994; Taylor & Morton 1996) and, in the latter case, aggregative feeding was supposedly a response to shortages in prey items. Tan (2008) noted the opposite among *C. capucinus* in Thailand, proposing that the absence of aggregative feeding was due to high prey abundances and in the species' ability to exploit them.

These arguments suggest that the aggregative feeding behaviour exhibited by *C. capucinus* in Darwin Harbour's mangroves is associated with constraints on the availability and accessibility of gastropod prey. Moreover, the attempted predation of a conspecific further supports the notion that access to gastropod prey items is somehow limited in local mangrove forests. However, field observations often produce biases and overestimations on predatory interactions (Fairweather & Underwood 1983), and the conclusions reached here are based on only a few opportunistic field observations. As such, without further detailed investigation, it is well beyond the capacity of this article to explain these seemingly uncharacteristic behaviours.

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Book Review:
Fire: A Brief History. Second edition

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Reading a book about fire would seem a strange way of consoling oneself when a patch of native vegetation within a public reserve that one has nurtured for 20 years has just been decimated by fire, but this is in fact what happened to me last year. The Landcare patch was still black when I received a copy of the book to review.

This second edition of *Fire: A Brief History* is the most condensed in a series of five works collectively entitled 'Cycle of Fire' by prolific author Stephen J. Pyne. All his books explain in a 'scientific' manner that fires and humans (for which he uses the term "hominins" to include our earliest ancestors) are mutually linked and have now (page 182) "blurred into an almost biological symbiosis" dating back to the dawn of hominanity. Pyne makes it clear from the outset of this book (page x) that "Fire is widely recognized as a defining presence on Earth and an informing principle of the Anthropocene." Indeed, Pyne terms the present age the "Pyrocene" geological epoch.

This book takes the broadest view that fire is a force with which we are now inextricably tied. Pyne says (page 195) "We emerged out of the ice ages in the past, but we have created a fire age for the foreseeable future." Therefore, I took consolation in realising (page xv) "Fire is unique to earth and our seizure of it unique to humanity." Now fire is everywhere, and we humans *need* it to be everywhere. Indeed, Pyne extends his co-evolutionary concept in arguing that fire actually directed ancient human evolution when it made food accessible that was otherwise too toxic or too tough to consume (e.g. page 24) "It released the skull from having to brace the enormous muscles required to chew uncooked foods, thus perhaps allowing the skull to swell." Down the evolutionary pathway, Pyne considers (page 49) "A properly burned land was the emblem of human stewardship."

However, after reading this book, my initial comfort was replaced with a sense of discomfort about several matters.

The first is that Pyne has himself become so entwined with fire over his long career, that he now anthropomorphises it (e.g. page 19) "Anthropogenic fire has had to understand itself in ways natural fire never has."

The next is that the language itself renders the book distant from its message. Some sentences are overly florid (e.g. page 15) "Fire has prowled through the landscape of

Earth's history as a bear might search out berries, grubs, and fish; roaming or hibernating with the seasons, growing fat and thin with the yearly offerings." and (page 30) "Charcoal is the spoor of early hominins." Whereas incongruously, others confront like a university text wherein the student needs a dictionary for every word (e.g. page 197) "In a sense they resemble non-Euclidian geometries, each yielding complete explanations based on their assumed axioms."

My next concern is the way Pyne views fire as a 'necessary' process for ecological landscaping. This may be so, but its benefits need to be balanced against the (human and wildlife) losses it brings. Pyne argues that organisms adapt to fire regimes, which they probably do as an entire species, but today organisms also face multiple other threats that, when combined with fire, could easily push them to extinction.

The next is Pyne's oft-repeated view that lands long-deprived of fire somehow degenerate when a closed climax forest is attained (e.g., page 62) "Here the abolition of aboriginal fire has caused coniferous woods to thicken, the prairie to contract, and aspen groves to collapse, smearing a once dappled landscape into a common green gunk." The message is that closed climax forest isn't patchy. However, this "common green gunk" supports a far greater diversity of plants and animals and ecological processes than land subject to frequent fire does. Indeed, fire is not the only process that creates openings in climax forests – landslides, death of massive trees, and tree falls caused by cyclones and megastorms also create openings in climax forests.

My last concern is Pyne's decidedly unscientific disdain for those park managers who have advocated for the exclusion of fire. He demeans them as "academic foresters" again and again. For example (page 196): "The only fire department at a university is one that sends emergency vehicles when an alarm sounds", and (page 196) "Yet coming out of temperate Europe, they hated and feared fire and sought to learn about it only in order to eliminate it", and (page 196) "Instead they strove to exclude fire as fully as possible, and even suppressed experimental data that suggested fire's value." From his own theoretical co-evolution with fire, Pyne now evidently holds a strong view that fire is paramount to maintaining biological diversity and, as a corollary, its exclusion is a really bad idea for conservation management. For example (page 171) he says "In naturally fire-prone areas or places that have long known anthropogenic fire, removing all fire, the good as well as the bad, has trashed biotas and made suppression self-defeating." Personally, I think these managers must have been well-intentioned; perhaps they had other motivators – such as landcarers wanting to nurture the richness and beauty of a majestic, intact, old-growth forest.

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